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Speed Benefits of Tilt-Rotor Designs for LHX

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Speed Benefits of Tilt-Rotor Designs for LHX

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I. EXECUTIVE SUMMARY

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A. PURPOSE

The purpose of this study is to compare the merits of an advanced helicopter and a tilt-rotor aircraft for light utility, scout, and attack roles when employed in combat operations envisioned for the year 2000 and beyond. The study also addresses certain acquisition issues that would be relevant to selection of a tilt-rotor configuration for the LHX.

This effort extends the LHX program definition tasks previously reported in SPC Report 700, LHX Helicopter Study (U), April 1981, and SPC Report 730, Design Speed Considerations for LHX (U), September 1981. It compares the baseline helicopter design described in SPC Report 730 to a tilt-rotor aircraft with identical payload, endurance, vertical flight performance, and mission equipment. Designs were configured with speed as the primary performance variable, but other important differences result from dissimilarities of the configurations or are consequences of the contrasting design speeds. Both the primary and consequential differences are considered in the analysis.

This assessment was sponsored by the Director, Aeromechanics Laboratory, U.S. Army Aviation Research and Development Command (AVRADCOM), and conducted in coordination with the Advanced Systems Research Office at Ames Research Center, Moffett Field, California; the Applied Technology Laboratory at Ft. Eustis, Virginia; and the Combat Developments Directorate of the U.S. Army Aviation Center, Ft. Rucker, Alabama.

B. BACKGROUND AND SCOPE

The history of warfare shows a continuous trend of increasing lethality and mobility of combat forces. This trend has produced a general decrease in the density of forces on the battlefield but no lessening of the need to attain force superiority by rapidly concentrating combat power. This historic pattern has been a result of technical improvements in the materiel of warfare that provide the means to locate targets, displace forces, employ weapons, and attain kill rates at increased tempos of battle. A high rate of technological advancement in recent decades has accelerated these trends and has resulted in projections of air land combat operations over greatly extended battlefields and at increased intensities of battle by the year 2000. Aggressive action by materiel acquisition managers is needed now to procure the advanced combat systems needed for future battlefields.

In order to ensure that performance requirements for new materiel are specified to satisfy the demands of future battlefields, the U.S. Army Training and Doctrine Command (TRADOC) has established a Concept Based Requirements System. This system is designed to ensure that new combat materiel is developed to meet the needs of future battles rather than merely correcting past or current deficiencies. If this system is to be successful, it is imperative that the technical community fully pursues and validates technical alternatives in the various mission areas so that our military leaders will have the option of specifying and realizing required capabilities. The LHX[1] is one of the first major materiel acquisitions being defined within the scheme of the Concept Based Requirements System.

The merits of speed for LHX were evaluated and reported in SPC Report 730, Design Speed Considerations for LHX (U) September 1981, for three advanced helicopter configurations. This report demonstrated that speed had increasing value for

[1]For this analysis, "LHX" refers to a family of light utility, scout, and attack aircraft with the configuration alternatives limited to an advanced helicopter and a comparable tilt-rotor. The basis for this candidate selection is described in SPC Report 730.

11 different mission classes that broadly encompass the intended LHX roles. It was also shown that cost increases with speed at a rate that results in a greater military worth for a 220-knot helicopter than for a 185-knot helicopter, but that the military worth of a 250-knot compound helicopter is essentially equal to that of the 220-knot helicopter. From this data, it could be concluded that helicopter speeds beyond 250 knots would have been judged to have lower military worth for the spectrum of LHX missions considered. Recent technical successes with the XV-15 tilt-rotor aircraft have demonstrated that helicopter vertical flight efficiencies and airplane horizontal flight efficiencies can be achieved or approached with a tilt-rotor design. Since the tilt-rotor concept offers a different cost-speed relationship than that of helicopters, assessment of a tilt-rotor LHX variant was warranted.

This task is one element of the LHX definition process that focuses on speed-related technology and the potential operational implications of speed for LHX. The task is intended to assist technology managers in bounding their technical efforts and not to be a determinant in establishing performance requirements for an operational LHX.

C. APPROACH

To perform this assessment, SPC:

- Established the technical parameters of an advanced tilt-rotor LHX alternative by adjusting a point design derived by the Advanced Systems Research Office, Ames Research Center, to match the payload and endurance parameters of a baseline advanced helicopter LHX.
- Conducted a map play of European and Middle East scenarios derived and reported in SPC Report 730 to identify parameters of representative light helicopter missions.
- Assessed the relative capabilities of the tilt-rotor LHX alternative using the Flight Path Analysis Model within both the established scenarios and subjectively derived variations in the threat and tactical play.

- Computed relative value of the tilt-rotor LHX compared to the baseline helicopter employing measures of effectiveness (MOEs) for the 11 mission categories reported in SPC Report 730.
- Established a first-order life cycle estimate for the tilt-rotor LHX.
- Computed military worth of the alternative designs by dividing relative value by relative cost compared to the lowest performing alternative.
- Assessed the problems of introducing a major configuration innovation into operational service.
- Evaluated the results to form a basis for conclusions.

D. TECHNOLOGY STATUS

The XV-15 research aircraft was designed to prove the tilt-rotor concept; it was never intended to be a prototype of an operational system. For this reason, many components were selected to minimize cost or risk. The result is that the XV-15 does not represent the specific range, payload mass fraction, or other efficiency parameters appropriate to an operational system.

The XV-15 tilt-rotor research aircraft is currently demonstrating the potential of the tilt-rotor concept. Hover performance and handling qualities have been shown to be comparable to modern helicopters. Conversion from helicopter mode to the airplane mode and reconversion have been accomplished with very low pilot workload. The airplane envelope expansion is in progress. The data for power required versus airspeed indicate that 300 knots can be achieved at normal rated power with cruise efficiency expected to be comparable to a turboprop aircraft.[2] An operational tilt-rotor

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[2] "Mission Potential of Derivatives of the XV-15 Tilt-Rotor Research Aircraft," presented at the 36th Annual National Forum of the American Helicopter Society, Washington, D.C., May 1980.

LHX would incorporate many technological advances over the XV-15 that are evolving in part from advanced development (AD) efforts identified in SPC Report 700, LHX Helicopter Study. Programmed efforts that would contribute to a more efficient operational tilt-rotor include the Advanced Composite Airframe Program (ACAP), Advanced Technology Demonstrator Engine (ATDE), and the Advanced Digital/Optical Control Systems (ADOCS). A more efficient rotor, now being developed for the XV-15, will result in a more advanced technology available for an operational system development. In addition, many other advances in aircraft subsystems for communication, navigation, weapons, survivability, and reliability are maturing and would be incorporated in an LHX engineering development (ED) that could begin in FY 1986.

The technology review conducted in support of the LHX assessment provided the basis for defining a baseline helicopter and a comparable tilt-rotor that vary only in speed performance and characteristics that are a direct consequence of speed or configuration differences. Payload, mission equipment, hot day performance, and other variables not related to speed were held constant. Weight mass fraction, rotor performance, drag projection, engine specific power and fuel consumption, and mission equipment were projected assuming optimistic results from AD programs now in progress or scheduled to be completed to support an FY 86 ED start.

Some uncertainties remain regarding the suitability of tilt-rotor designs for the LHX role. These uncertainties do not relate to technical feasibility but involve operational service considerations such as downwash velocity limits, nap-of-the-earth (NOE) flight profile capabilities, and other mission-related considerations now being evaluated with flight tests and associated analyses.

One area of uncertainty warrants specific mention. Downwash from aircraft in a vertical flight mode (or hover) has been a constraint to operational utility when downwash velocities exceed about 40 knots. At higher velocities, the downwash disturbs soil, rocks, water, and debris and creates distress by creating hazards to nearby troops or reingestion in the rotor-induced flow. In addition, disturbed sand, dust, snow, and vegetation can present an undesired distinctive signature or obstruct the visual ground reference of the flight crew. Upper limits of downwash velocity are not absolutely defined and are related to associated mass flow. Down-wash velocities are determined by disc loading (vertical thrust divided by rotor swept area);

disc loading has frequently been a specified constraint on new designs. UTTAS and Advanced Attack Helicopter (AAH) designs were constrained to 8 lb/ft^2; operational experience with systems exceeding about 10 lb/ft^2 (CH-54, for example) has resulted in substantial distress. The XV-15 operates with a disc loading of about 13 lb/ft^2. If this level is found to be too high, a lower value is a design discretion that can probably be accommodated with little or no penalty for an LHX class design.

The technology essential to a successful tilt-rotor has been developed primarily by Bell Helicopter with funding support of the U.S. Army and the National Aeronautics and Space Administration (NASA). Although the XV-15 program has been conducted with broadly disseminated disclosure of development details, expertise and experience in this technology are not found elsewhere in the industry, except to a partial degree at Boeing Vertol. NASA and the Army have sponsored some tilt-rotor effort with Boeing Vertol over the past 12 years to establish a broader technical base than a single contractor. In fact, Boeing Vertol recently won a competitive award for development of an advanced rotor for the XV-15. The result of these circumstances is that there is a competitive base of four or more contractors who could compete for an advanced helicopter design—but a marginal maximum of two for a tilt-rotor design.

The two designs that were defined have maximum cruise capabilities of 185 and 300 knots, respectively. The 185-knot helicopter is considered the baseline design; it represents performance that could be expected from historical trends without particular emphasis on speed. Its speed performance is equivalent to the Soviet Hind, which has been operational since 1973.[3]

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[3]Defense Intelligence Agency, Rotary-Wing Aircraft (Trends) - Eurasian Communist Countries (U), DST-13405-075-78, November 1978, Secret/WN.

E. MISSION PARAMETER GENERATION

1. Tactical Scenarios

To provide a valid set of operational scenes from which realistic mission parameters could be derived, five representative scenarios described in Design Speed Considerations for LHX were played as detailed wargames. These games were played on tactical terrain maps by experienced analysts with former combat experience to infantry brigade and aviation group command levels. Appropriate threat levels were played for the near-term, mid-term (1985-1990), and long-term (2000). Three European and two Middle East scenarios were derived from the latest concept documents that define air land combat projected for the time frame when LHX is expected to be operational.

2. Mission Parameters

Approximately 280 detailed missions were derived from these scenarios to span the full range of light utility, scout, reconnaissance, attack, and medical evacuation missions envisioned for the LHX family. Detailed flight parameters, including flight modes. time lines, and fuel consumption rates, were computed and accounted for using a programmed Flight Path Analysis Flow Model. This model accommodates intervisibilities between opposing ground and air weapons systems and can compute aircraft hit and attrition data for any given level of aircraft system vulnerability to any specified threat. Since speed, especially within the band assessed here, is not the principal determinant of survivability and since the influence of aircraft performance on survivability was being separately addressed in a parallel study, aircraft attrition was not computed with the model for this assessment.

F. RELATIVE VALUE ASSESSMENT

In order to provide continuity with previous quantitative analyses that assessed LHX alternatives, this analysis followed the methodology of those studies in evaluating the relative value of the tilt-rotor as an alternative to an advanced conventional helicopter. In SPC Report 730, Design Speed Considerations for LHX, it was observed that speed influenced or tended to influence four basic value parameters. These are related to missions that are sensitive to:

- Response time
- Time on station
- Sortie generation (productivity)
- Survivability.

For the first three value parameters, 11 different mission classes were identified that reflected the influence of speed on these parameters. For each of the mission classes, a schematic of the mission was drawn, representative critical inputs were identified, a definitive MOE was derived, and a principal mission variable was selected. The MOEs were plotted against the principal mission variable over a representative range of values encountered in the scenarios. At a specific mission variable data point, relative improvement factors were computed for the MOE appropriate to that mission comparing the percentage improvement in effectiveness of the 300-knot tilt-rotor design over the 185-knot baseline helicopter design. Specific mission variable points were selected to be representative of missions most commonly encountered in the battle scenarios and did not reflect the most demanding missions (which would tend to favor the higher performance candidates).

The selected mission classes and the relative improvement percentages follow:

Mission Parameter	Mission Class	Percent Improvement 300-kn Tilt-Rotor
Time Response	Time to scene	46.0
	Medical evacuation	44.0
	Mass to scene	158.0
	Airmobile intercept	120.0
Time on Station	Surveillance	40.0
	Security	68.0
	Airborne jammer	33.0
	Presence on scene	44.0
Sortie Generation	Attack	31.0
	Troop displacement	41.0
	Resupply	69.0
	Average Improvement:	63.1

Since all of these mission classes are not of equal importance, it was recognized that they should not be weighted equally; simple averaging results in equal weighting. In order to test and display the sensitivity to weighting the tasks, weighting factors were derived with a simplified Delphi technique, and the MOEs were then recomputed using the weighting factors. These recomputed MOEs are displayed below with their associated weighting factors in comparison to the initial MOEs:

Mission	Unweighted MOEs 300-kn Tilt-Rotor	Weighting Factor	Weighted MOEs 300-kn Tilt-Rotor
Time to scene	46.0	1.2	55.2
Medical evacuation	44.0	1.0	44.0
Mass to scene	158.0	1.3	205.4
Airmobile intercept	120.0	0.7	84.0
Surveillance	40.0	0.9	36.0
Security	68.0	0.9	61.2
Airborne jammer	33.0	0.8	26.4
Presence on scene	44.0	1.0	44.0
Attack	31.0	1.3	40.3
Troop displacement	41.0	1.1	45.1
Resupply	69.0	0.8	55.2
Average	63.1	1.0	63.3

As is evident, the relative values measured by the specified MOEs are essentially insensitive to the selected weighting factors. To further test sensitivity, other weighting factor variations were derived and tested without substantially different results.

While vulnerability is an important value parameter that could be expected to be influenced by speed, no comprehensive MOE to display this sensitivity was identified that was broadly applicable. Since the relationship of speed and maneuverability is being separately considered under a contract with Grumman Aircraft Corporation, the speed/vulnerability issue was not treated here. However, SPC Report 730 does show that a speed advantage is important in air-to-air engagements with other helicopters because it affords the option of controlling the conditions of any engagement to advantage. Against ground-to-air threats, speed tends to reduce exposure to threat weapons in some threat conditions, but this advantage tends to be offset by a larger presented area. In summary, the value of speed in air-to-air engagements against other helicopters was found to be favorable, but the relative advantage was not quantified. Against ground threat weapons, the value of speed was not established.

G. RELATIVE COST ASSESSMENT

Acquisition and life cycle costs were computed employing standard parametric techniques for the two candidate designs. These cost estimates should be considered more valid in a relative sense rather than as absolute values. To compensate for technical uncertainties in the final design of the tilt-rotor, complexity factors were used to bound the range of this uncertainty. The 185-knot helicopter was used as the baseline from which these complexity factors are applied. The baseline tilt-rotor cost assumes comparable complexity to the baseline helicopter; the alternative tilt-rotor costs assume increased complexity of the tilt-rotor unique subsystems. The average unit acquisition and 20-year peace time life cycle costs (millions, FY $82) are presented below assuming an acquisition quantity of 4,000 aircraft:

AVERAGE COSTS (Millions, FY 1982)

		300-kn Tilt-Rotor		
	185-kn	Baseline T-R	25% Complexity	50% Complexity
Acquisition	2.45	3.83	3.98	3.93
Other life cycle	5.47	5.98	6.09	6.27
Total	8.05	9.81	9.97	10.2
Percent increase over baseline		21.9	23.9	26.7

H. MILITARY WORTH

Relative value and costs are presented in many formats to display comparative cost effectiveness measures of alternative systems. One frequently used technique is to designate the dividend of relative value and relative cost as "military worth" and use that number as a basis for selecting between alternatives. Using the relative values and costs presented above, military worth indices were computed with both unweighted and weighted MOEs and are displayed below:

MILITARY WORTH

Average MOEs

	15% Complexity	25% Complexity	50% Complexity
$\frac{\text{Relative Value}}{\text{Relative Cost}}$	$\frac{1.631}{1.219} = 1.34$	$\frac{1.631}{1.239} = 1.32$	$\frac{1.631}{1.267} = 1.29$

Weighted MOEs

	15% Complexity	25% Complexity	50% Complexity
$\frac{\text{Relative Value}}{\text{Relative Cost}}$	$\frac{1.633}{1.219} = 1.34$	$\frac{1.633}{1.239} = 1.32$	$\frac{1.633}{1.267} = 1.29$

Military worth is essentially insensitive to uncertainties in the relative complexity of an operational tilt-rotor aircraft compared to a conventional helicopter.

I. CONCLUSIONS AND RECOMMENDATIONS

This assessment supports earlier findings that increased speed contributes to the potential value of an aircraft for virtually all battlefield roles envisaged for LHX. This fact is most clearly discernable when performance is considered for a combat operation rather than only a mission at a time. Since high-speed designs meet battlefield urgencies that tend to be most critical in combat and can operate with efficiency over greater ranges (throughout the extended battlefield) better than conventional helicopters, increased speed should be an area of emphasis for the Army's aeronautical technology program.

The success of the XV-15 program has received worldwide acclaim. It is difficult to find technical or operational bases on which to exclude tilt-rotor configurations from consideration for LHX. Even critics and those with vested interests in other alternatives can find few valid concerns with a tilt-rotor LHX. The principal difficulties would be structuring an adequately competitive acquisition or justifying such a major program as a sole source award to the XV-15 contractor.

Although a substantial uncertainty remains regarding the speed-cost relationship, it is difficult to visualize a cost difference between an advanced helicopter and a tilt-rotor LHX that would be as great as the difference in value identified in this assessment. If a speed advantage is not deliberately conceded to the Soviets, and if the need for better range/speed capabilities for certain important but infrequent special operations (e.g., rescue, deep raids, covert extractions) is considered, an emphasis on increasing speed performance is assuredly warranted.

The results of this assessment lead to the following conclusions:

- Evolving technology could provide an LHX with speeds up to twice those of the most modern operational helicopters with an initial operational capability by the mid-90s.
- The value of speed is most apparent when performance throughout the period and in the context of a full battle day is considered rather than by mission or by mission segment.

- If the final requirement validates the need for greater speed rather than the minimum unit cost alternative (conventional helicopter), the tilt-rotor appears to be the solution with the greatest military worth for normal battlefield missions and with the greatest capability for meeting the uncertainties of future needs.
- If a need for 300-knot speeds for LHX is validated, the lack of a competitive technology base for tilt-rotor designs may present difficulties during the early acquisition phases.

It is recommended that Army aviation technology efforts be structured to:

- Provide results from the ADTE, ADOCS, Integrated Technology Rotor Program (ITRP), ACAP, and tilt-rotor programs to support an ED start for LHX in FY 86.
- Expand the tilt-rotor program to expose the XV-15 research aircraft to simulated combat missions and to broaden the technology base beyond the current technical base.
- Establish a "most likely" power requirement for the ATDE promptly so that the user's need will not be delayed or constrained by technical capabilities.

II. BACKGROUND AND METHODOLOGY

SPC Report 700, LHX Helicopter Study (U), April 1981, identified the magnitude and time span for large quantitative and qualitative deficiencies for light helicopters as beginning in the mid-80s and becoming increasingly severe through the 90s. This study postulated an aggressive acquisition strategy for a new helicopter series, designated LHX, and identified a technology base structure that could support an ED start in FY 85 or 86.

Subsequently, the military worth of speed was assessed in SPC Report 730, Design Speed Considerations for LHX (U), September 1981, to provide direction and guidance to AD efforts aimed at LHX. This study considered advanced rotary wing concepts exclusive of X-wing and tilt-rotor technologies. It was shown that speed contributed increasingly to military utility up to the technical limit assumed (250 knots) but that inordinate costs for speeds beyond 220 knots resulted in essentially equal military worth for rotary wing candidates in the 220-250 knot speed range. The technology of X-wing was evaluated as too immature for consideration as an LHX candidate. However, tilt-rotor has displayed excellent progress in flight tests with the XV-15; this success warranted consideration of a tilt-rotor configuration for LHX because tilt-rotor designs achieve higher speeds at a potentially lower cost than more conventional rotary wing configurations.

This study examines the potential military worth of a tilt-rotor LHX; it employs the same methodology and costing ground rates derived in SPC Report 730. Because many aspects of the relevant technology, advanced threats considered, scenario generation, and MOEs are not fully reported herein, this report does not stand alone and should be considered in conjunction with SPC Report 730.

PURPOSE

- Extend the *Design Speed Considerations for LHX (U)* analysis to include tilt-rotor speed potential
- Assess the potential of tilt-rotor configurations for LHX
- Develop an acquisition strategy to introduce tilt-rotor capabilities into Army operations

This chart defines the methodology for this report. The baseline helicopter used as a basis of comparison is the 185-knot advanced helicopter derived in SPC Report 730.

The military worth of the alternatives is defined as the dividend of relative value and relative life cycle costs.

METHODOLOGY

- Define a tilt-rotor LHX configuration employing ground rules consistent with the rotary wing alternatives reported in SPC Report 730
- Compare the military worth of a tilt-rotor LHX to an advanced rotary wing baseline design employing multiple measures of merit
- Assess the suitability of a tilt-rotor configuration for the LHX
- Identify and assess alternative strategies to acquire an operational tilt-rotor aircraft

III. TECHNICAL CONSIDERATIONS

Until recent XV-15 successes, the principal technical risks regarding the viability of tilt-rotor designs have been aeroelastic stability of the rotor system and handling qualities. The prudent pace and scope of the analytic, wind tunnel, and flight test efforts associated with the XV-15 program have essentially resolved these uncertainties, at least for aircraft of XV-15 size or somewhat smaller.

Secondary uncertainties related to weight fractions, drag, cost, and complexity will be encountered in any engineering effort to develop an operational tilt-rotor aircraft.

TILT-ROTOR TECHNICAL RISKS

PRINCIPAL

Rotor aeroelastic stability	– essentially resolved
Handling qualities	– essentially resolved

SECONDARY

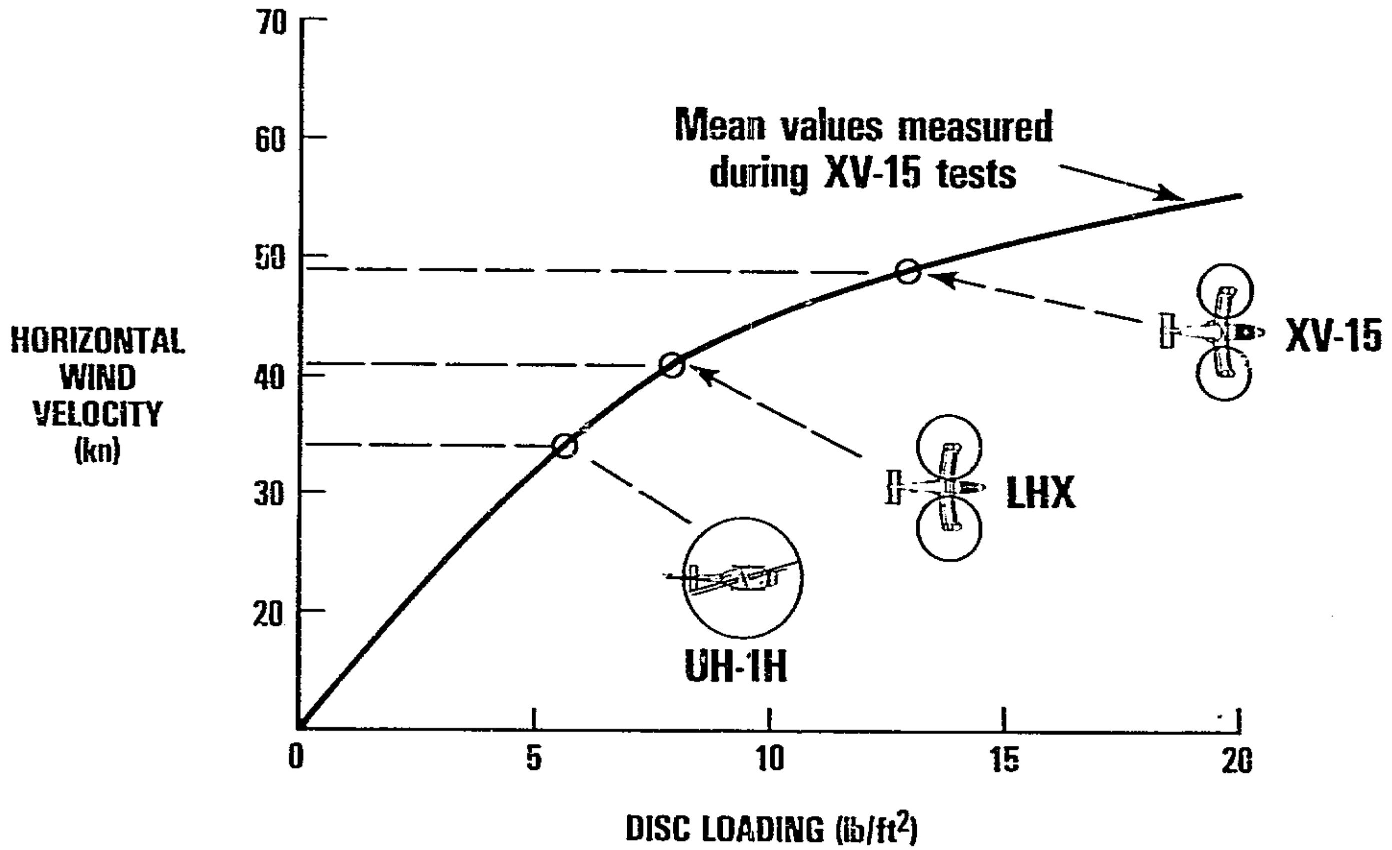
Disc loading limits	– primarily operational
Weight fractions	– low to moderate
Drag	– low
Complexity	– low to moderate
Costs	– continuing concern

This chart depicts the horizontal velocity across the ground generated by the XV-15 at various gross weights. For comparison purposes, it also depicts a tilt-rotor LHX designed to an 8-lb/ft^2 criterion. It can be seen that such a constraint would not be a substantial departure from the XV-15 experience. These two tilt-rotor designs are compared to the current UH-1H at a gross weight of 9,500 lb. In order to operate a 10,000-lb LHX at a disc loading of 8 lb/ft^2, it is necessary to increase the rotor diameter of the XV-15 from 25 to 28 feet, a 12 percent increase.

Most distress from rotor wash derives from vertical downwash impacting the ground and then spreading outward along the ground disturbing debris and loose objects. Disc loading determines downwash velocities for aircraft in hover flight. It has been the Army's experience that disc loadings above about 8 lb/ft^2 result in operational distress from disturbed debris, sand, water, and loose objects at landing and takeoff sites; recent helicopter developments have been constrained to disc loadings of not more than 8 lb/ft^2. The XV-15 design disc loading was established at 15 lb/ft^2. This parameter is a design discretion that generally optimizes at higher values for larger aircraft. Drive systems scaling factors result in adverse weight fraction penalties for larger rotors. Lower disc loadings could be achieved for an operational tilt-rotor aircraft sized about as the XV-15 or smaller with little or no weight fraction penalty. Lower disc loading is obtained by increasing rotor diameters, which could require continued caution regarding rotor aeroelastic stability. This concern should be very small for an aircraft below 10,000, or perhaps, 15,000 lb in gross weight but should be an area of substantial caution for higher gross weights.

Disc loading limits for a tilt-rotor LHX configuration merit specific attention and are discussed with the next chart.

DISC LOADING EFFECTS



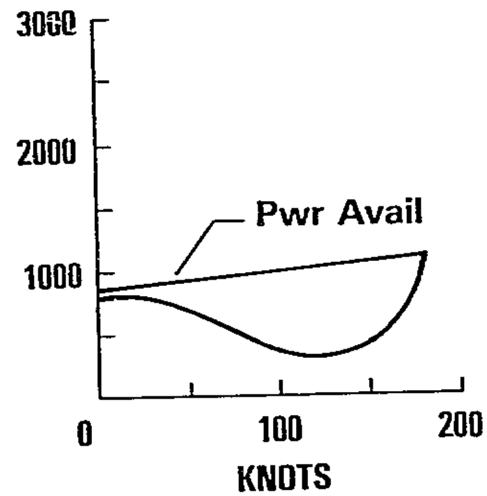
This chart displays principal parameters for the baseline 185-knot advanced helicopter derived in SPC Report 730 and a comparable tilt-rotor aircraft. Payload, flight endurance, visionics, and ambient design point of the two systems are identical. Both designs project optimistic assumptions for propulsion, flight controls, structures, drag reduction, and other component efficiencies. Mission equipment (e.g., weapons, APUs, and troop seats) is counted as payload to allow utility, scout, and attack variants to be treated similarily in subsequent analyses.

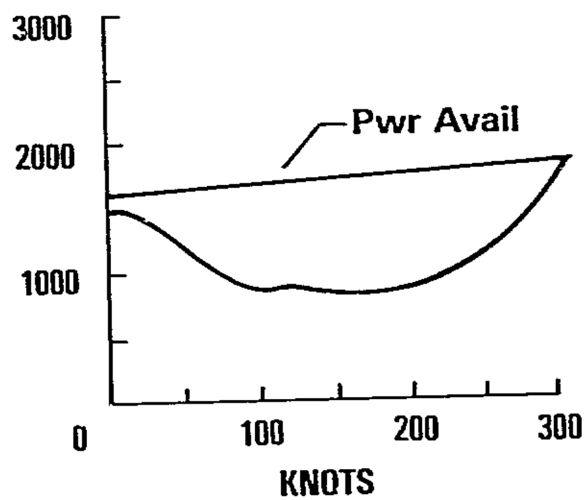
The principal performance difference between these two aircraft is speed. The consequences of speed (higher costs, greater fuel consumption, and larger presented area) are recognized in subsequent analyses.

One other important difference warrants particular mention. The baseline helicopter (and the other alternative rotary wing designs presented in SPC Report 730) has a disc loading of 8 lb/ft^2. This disc loading has been an upper limit constraint for recent Army helicopter designs such as UTTAS, AAH, and Advanced Scout Helicopter (ASH).

The 13.1 lb/ft^2 disc loading selected for this tilt-rotor alternative results in a balanced power requirement for vertical flight and 300-knot cruise. This higher disc loading also results in downwash velocities higher than with any system with which the U.S. Army has operational experience (CH-54 = 11 lb/ft^2). It is cited here because this parameter remains a discretionary design uncertainty regarding tilt-totor considerations. Operational implications of this design point selection were addressed earlier.

ADVANCED HELICOPTER/TILT-ROTOR
ALTERNATIVES





ORIGINAL PAGE IS
OF POOR QUALITY

	ADVANCED HELICOPTER	TILT-ROTOR
DGW (lb)	7,470	9,956
Inst Pwr (shp)	1,310	2,489
OWE (lb)	3,270	5,431
Fuel (lb)	1,500	2,025
PL (lb)	2,230	2,230
Fe (ft^3)	8.0	4.8
Disc loading (lb/ft^2)	8.0	13.1

*Drag factor (D/q) for airplane operating mode. No external stores.

IV. FLIGHT PATH ANALYSIS MODEL

An analytical model was developed and programmed to assess the impact of helicopter speed on mission times, fuel consumption, and exposure to fire. The missions are described by X, Y coordinates along the path and by the flight mode (e.g., NOE) desired as the helicopter flies from the current point to the next. A threat array is stored along with the line of sight (LOS) between each threat and the route points. For this model, intervisibility is an input parameter and not an integral computation. Using the helicopter speed and fuel consumption characteristics, the total time and fuel consumed are calculated. The model also keeps track of the time and fuel consumed for each flight mode used during the mission.

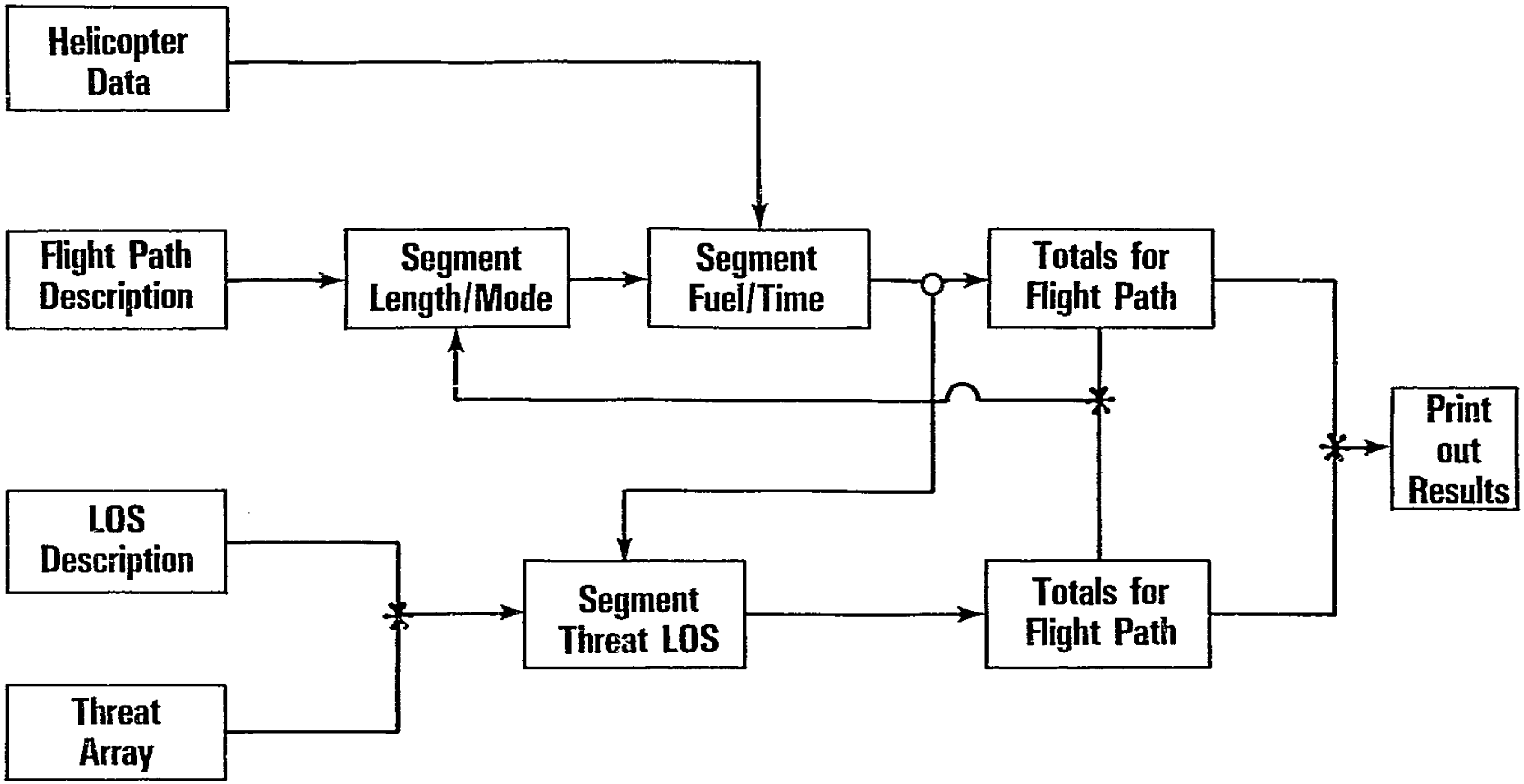
All of the flight paths assumed that the helicopters would fly evasive flight profiles whenever there was a potential of being exposed to fire. The flight mode would be NOE or pop-up hover when threats were most imminent. Since there was no speed differential among the helicopters in NOE, the exposure is identical for all the helicopter candidates during NOE or hover flight modes. For this reason, the exposure segments of the model had little relevance to this assessment and were not exercised. Relative vulnerability was addressed off-line.

FLIGHT PATH ANALYSIS MODEL

- ► Purpose
  - • To assess the effect of helicopter speed on the mission times, fuel consumption, and exposure to fire
- ► Model description
  - • Route point description of flight path
    - – X,Y coordinates
    - – Flight mode
  - • Threat array
    - – X,Y coordinates
    - – Threat type
  - • Intervisibility matrix
    - – LOS between threat and helicopter
  - • Helicopter characteristics
    - – Speed characteristics
    - – Specific fuel consumption by flight mode
    - – Shaft horsepower
    - – Maximum fuel load

The flow diagram for the flight path computer model is shown. For each segment of the flight path, the model computes the length of the segment, the time required to traverse the segment, the fuel consumed, and the exposure to enemy defenses. The model is simple and primarily solves the bookkeeping problem associated with the route point type calculations. The program is implemented on a microcomputer and is interactive with the user. Input parameters are readily varied, results are displayed for review on-line, and hard copy printouts of results are immediately available on demand. If exercised, intervisibilities would be computed and inserted from other off-line routines, such as ENGAGE or CARMONETTE, that contain digitized terrain maps of sufficient resolution.

FLIGHT PATH ANALYSIS MODEL FLOW DIAGRAM



This chart depicts a representative output of the Flight Path Analysis Model. It provides critical parameters for each mission on which analyses can be based but does not provide a direct basis for assessing the value of speed for any particular mission.

MOEs are identified subsequently, and an analytical basis for considering the relative value of speed for conventional helicopter and tilt-rotor LHX designs is provided.

SAMPLE MISSION TIME LINES
EUROPEAN SCENARIO, CORPS 86 DOCTRINE

Mission: Armed attack

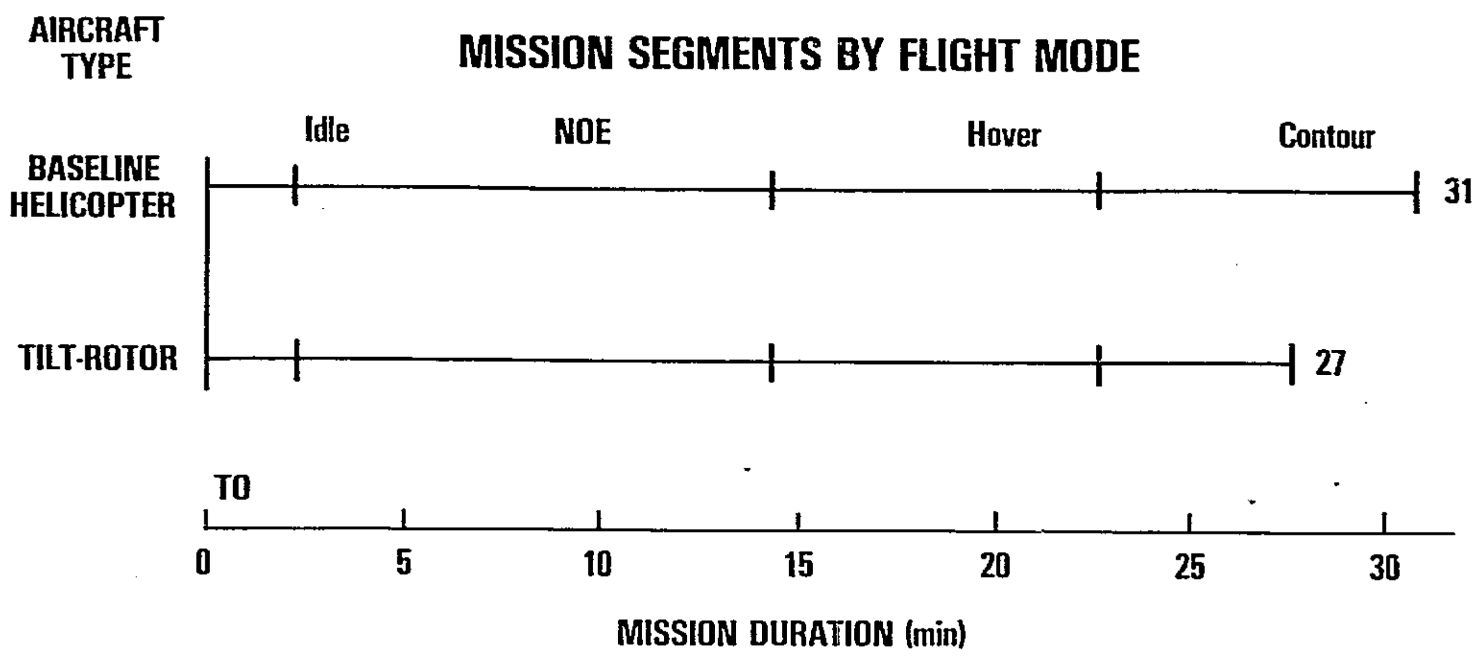
Mission distance: 72 km

MISSION FUEL REMAINING

Baseline helicopter: 119 min

Tilt-Rotor: 123 min

MISSION SEGMENTS BY FLIGHT MODE



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V. VALUE ASSESSMENT

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During game play conducted for and reported in SPC Report 730, it was observed that flight speed contributed or tended to contribute positively to four basic value parameters on missions for which time response, time on station, sortie generation (productivity), or survivability were significant considerations. One or more of these value parameters was an inherent element of virtually every mission generated by the scenario play.

To provide a basis for quantitative analysis, 11 representative mission classes were identified to illustrate the value of speed with selected mission variables for the three value parameters shown on this chart. For each mission class, an MOE was identified that provided a distinguishing, quantifiable measure of relative value for the 300-knot tilt-rotor LHX (vis-a-vis the 185-knot baseline candidate) as a function of an important mission variable. For each mission class, a schematic representation typical for that class was constructed, together with an MOE variation appropriate to the particular mission class. The results are depicted on the following 11 mission-specific charts, and then are summarized on an aggregated chart to provide an overall perspective.

No comparable means of assessing the influence of speed on survivability was identified. For this reason, the speed/survivability issue was assessed separately and quantified only selectively.

MISSION AGGREGATIONS

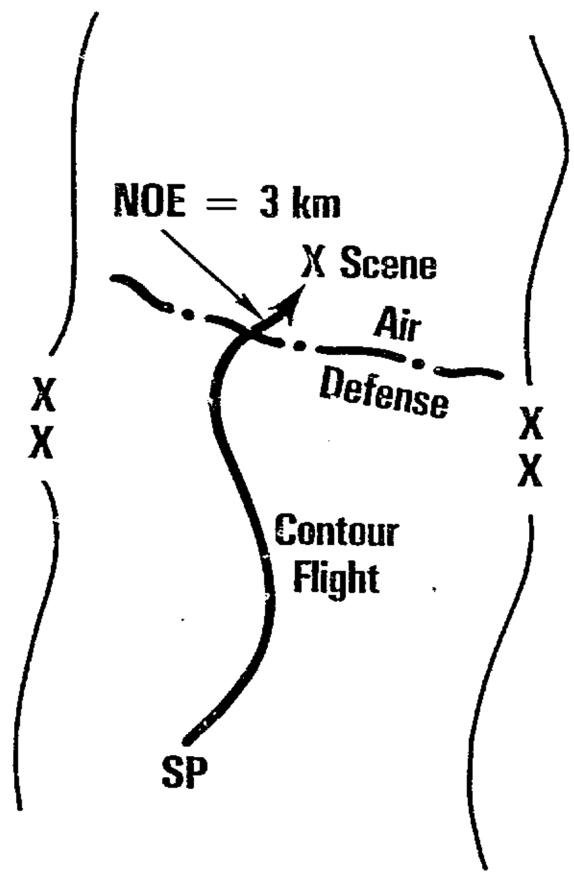
KEY PARAMETERS	TYPICAL MISSIONS
Response time	Time to scene
	Medical evacuation
	Mass to a scene
	Airmobile intercept
Endurance on station	Surveillance
	Security
	SEMA
	Presence on scene
Sorties delivered	Attack
	Troop displacement
	Resupply

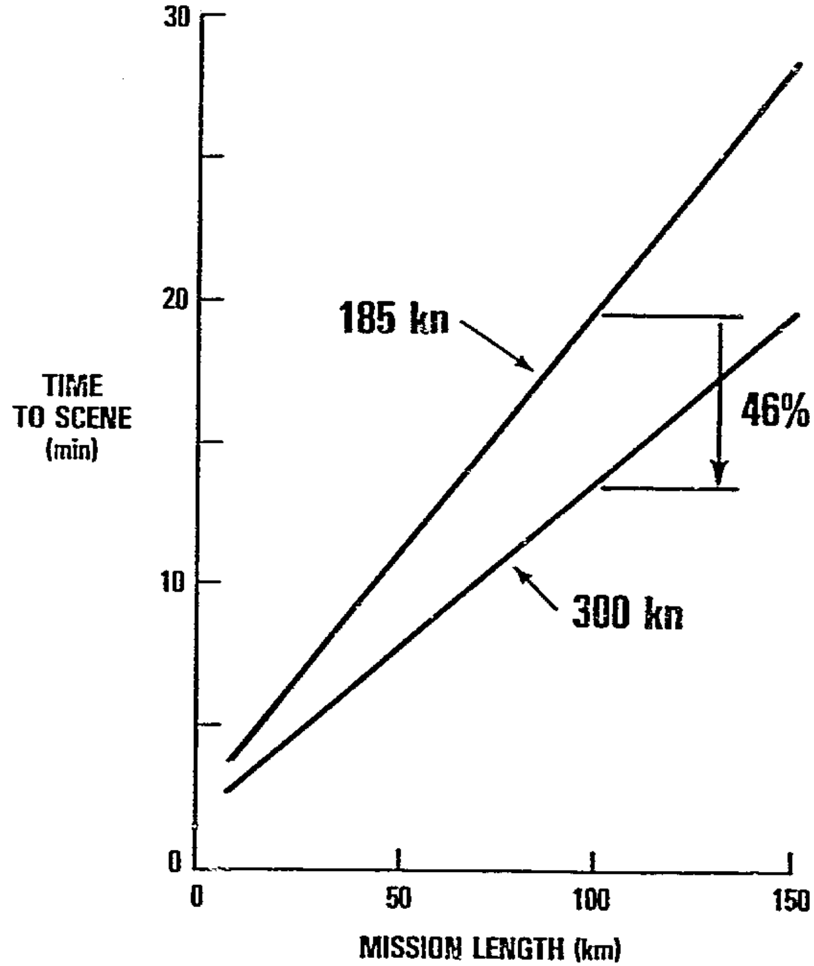
Each of the 11 mission classes is presented in a format similar to this chart's with the mission boundary conditions on the left and a measure of merit appropriate to the mission presented on the right as a function of a primary variable. A relative value improvement is displayed as a representative, but not extreme, value of the primary variable.

The facing chart is representative of a very common LHX mission in which a commander requires a person, a small element, a critical materiel item, or a key document to be moved from one location to another. This mission is, perhaps, the most fundamental in meeting the many urgencies of every battle.

This MOE would display little variation with mission length, but would tend to be reduced as greater proportions of the mission demanded NOE flight. Mission length was selected as the primary variable because fast response times will be an important factor on future battlefields that operate over extended distances and with increased tempo. Higher flight speeds are the only characteristic that can minimize response time under battle doctrines projected for the future.

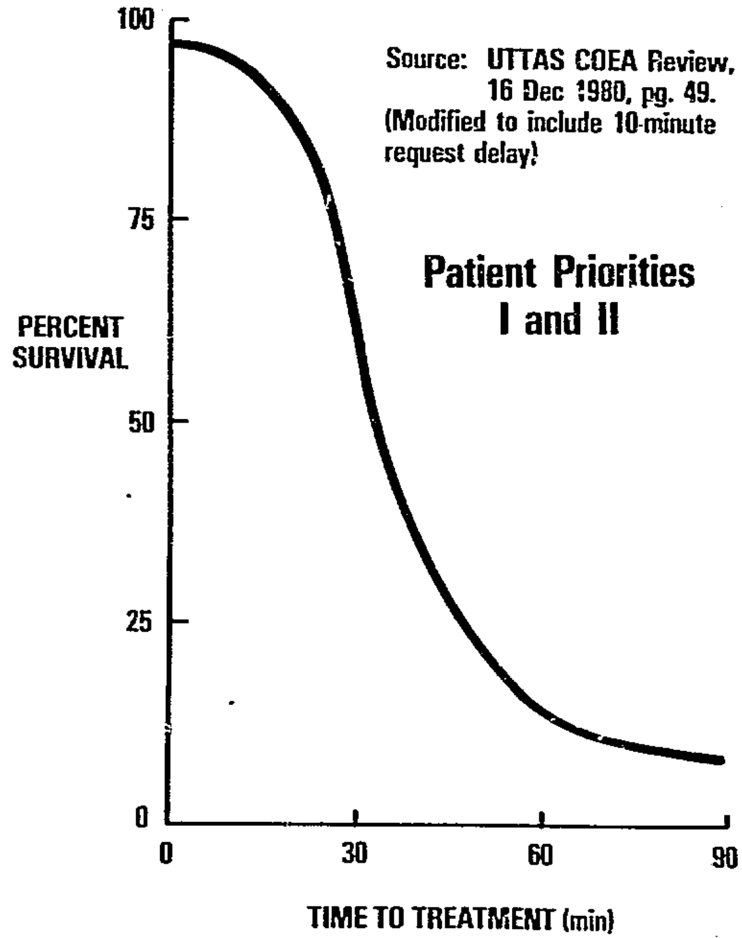
TIME TO SCENE

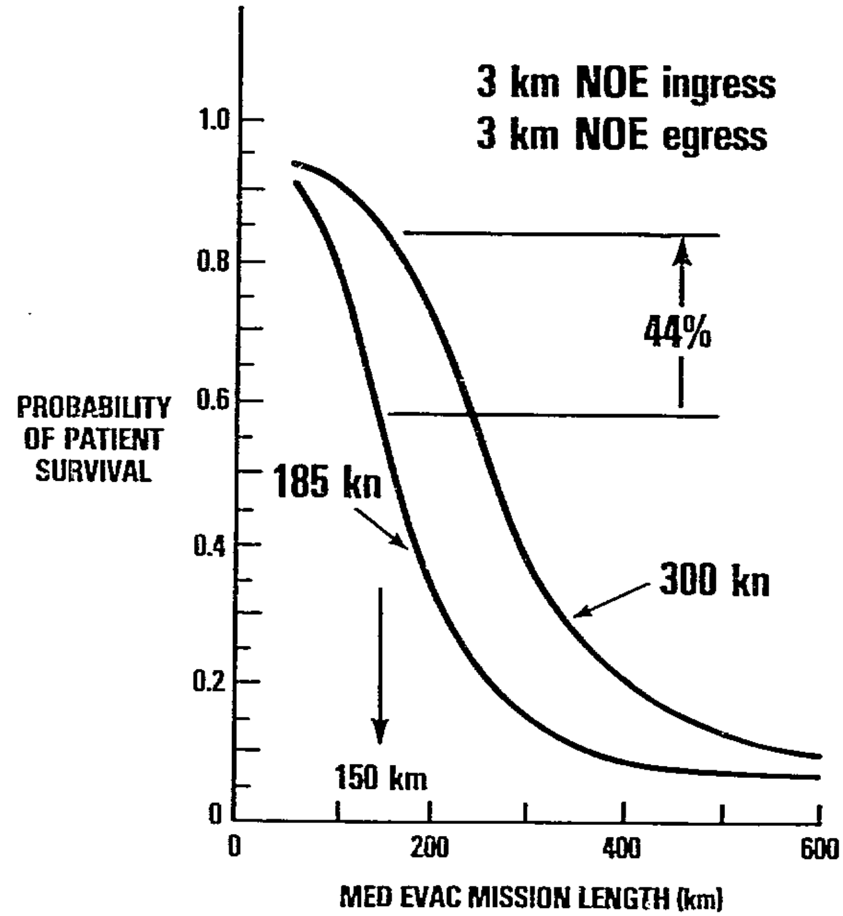




This is the classic mission for which helicopters first earned a crucial role in Army force structures. The survival rate curve as a function of time to treatment for casualties with potentially mortal wounds was derived from combat experience and the experience with civil injuries in shock trauma centers. Its validity has been approved by the U.S. Army Surgeon General.

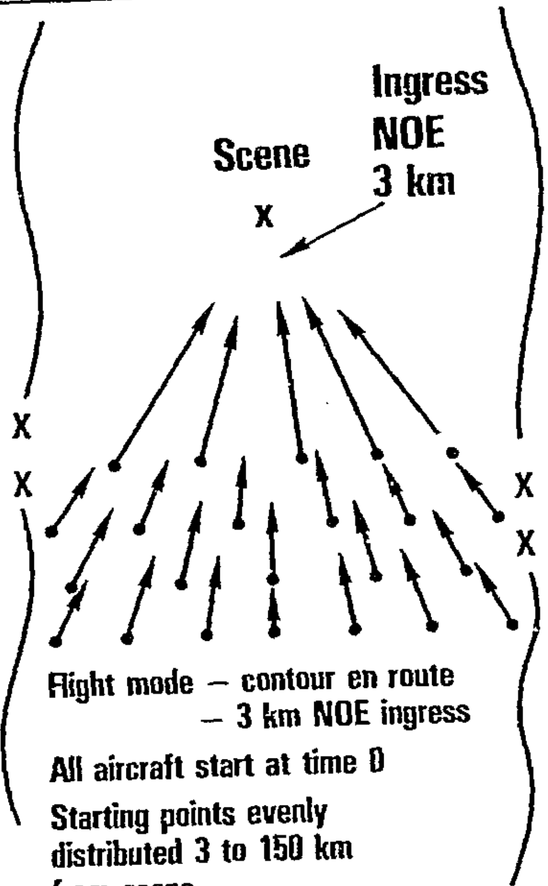
MEDICAL EVACUATION

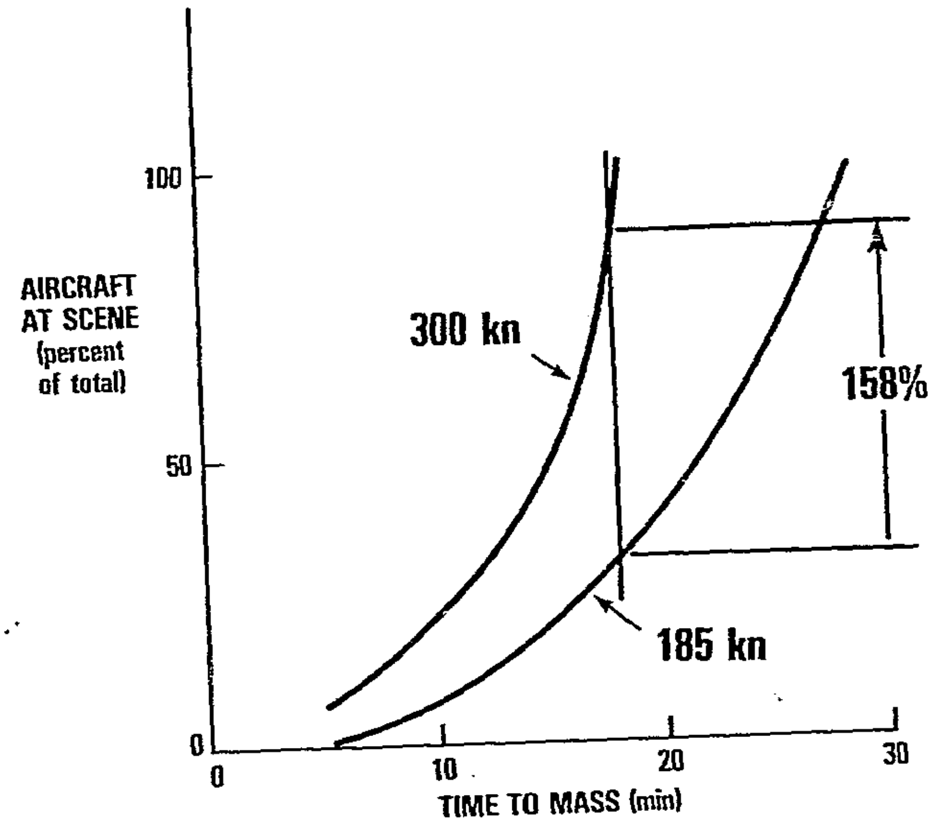




This class is representative of many missions that occur on the battlefield, especially in battle scenarios employing advanced doctrine. It could represent massing attack helicopters from dispersed locations, assembling helicopters to a mass medical evacuation urgency from dispersed sites, or massing dispersed forces to a critical battle scene. The selected MOE and principal variable are especially appropriate to this mission class.

MASS TO A SCENE





This class can represent either:

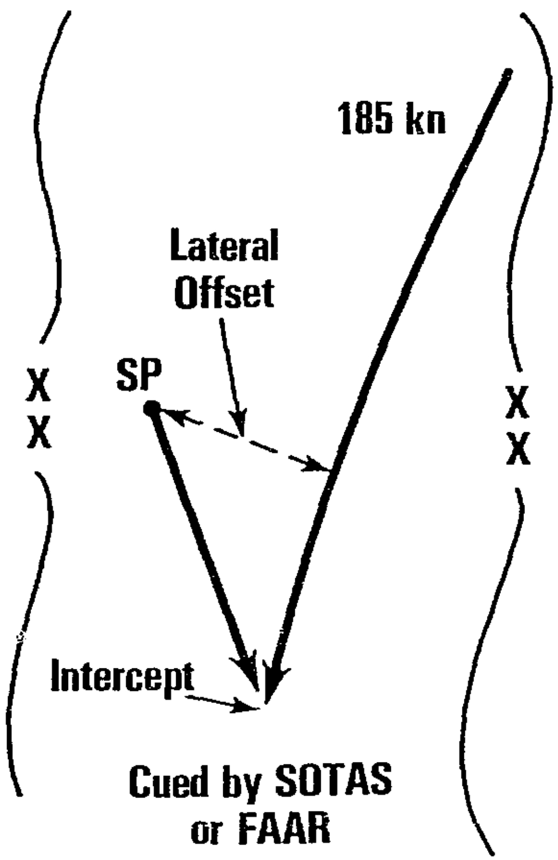
- An air-to-air intercept of a helicopter threat
- An airmobile reaction to a helicopter-inserted force.

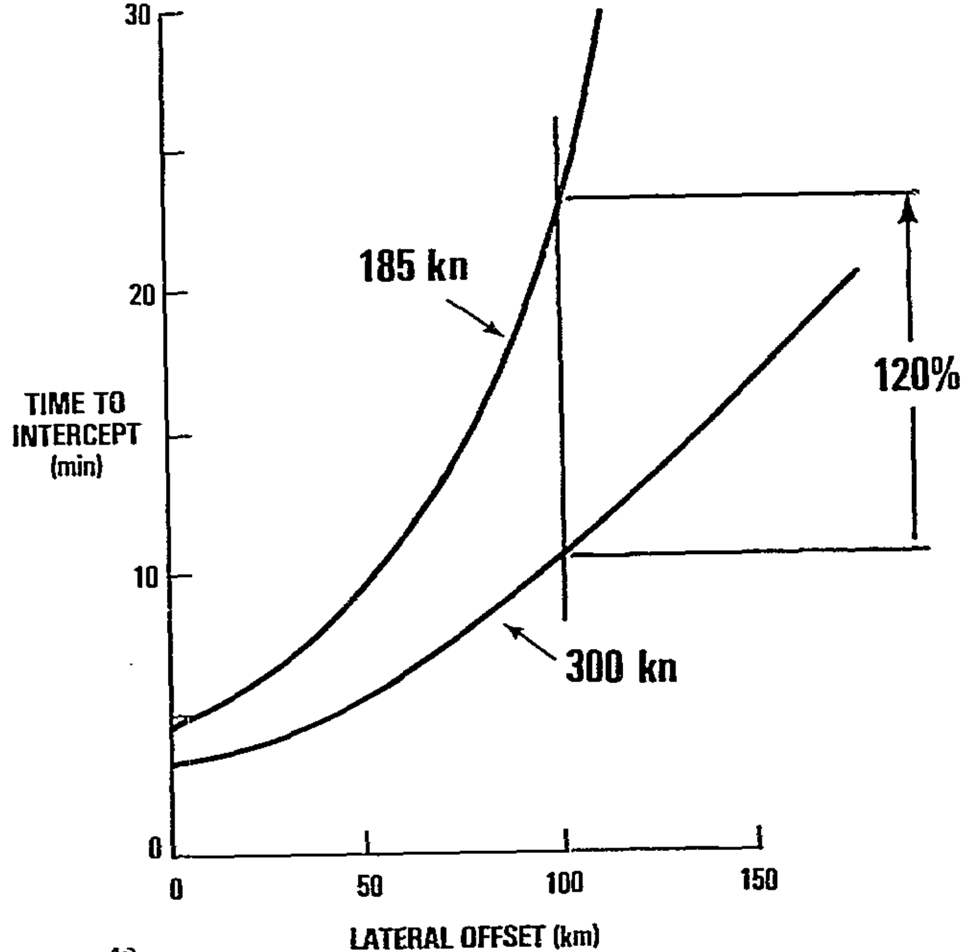
Both of these mission alternatives could be important. In general, this analysis assumed that Army helicopters would operate within the general air defense protection afforded other Army elements by organic air defense weapons (e.g., Roland, DIVADS, Patriot) and Air Force fighters. However, many situations occurred in scenario play in which helicopters were operating on flanks and in depth beyond ground air defense coverage and with time urgencies that precluded Air Force response.

In addition, Soviet doctrine envisions frequent employment of helicopter forces inserted into our rear areas; airmobile response will be the primary means of countering these elements before they disperse.

For these reasons, this mission class is considered a critical part of the speed issue.

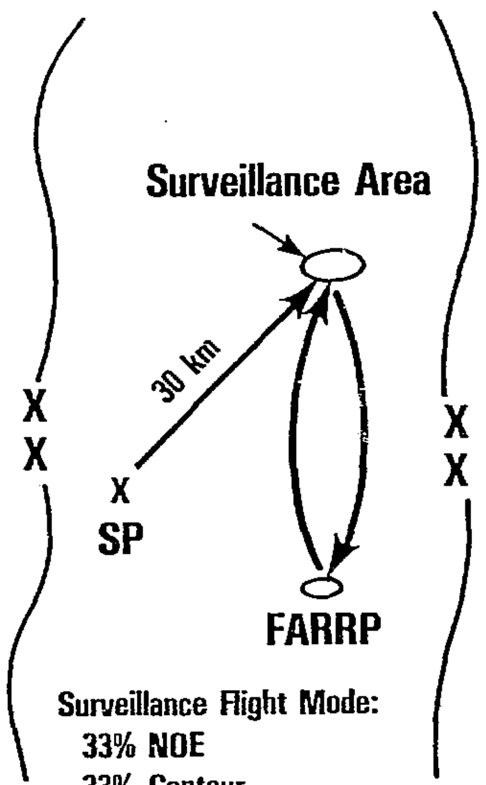
AIRMOBILE INTERCEPT





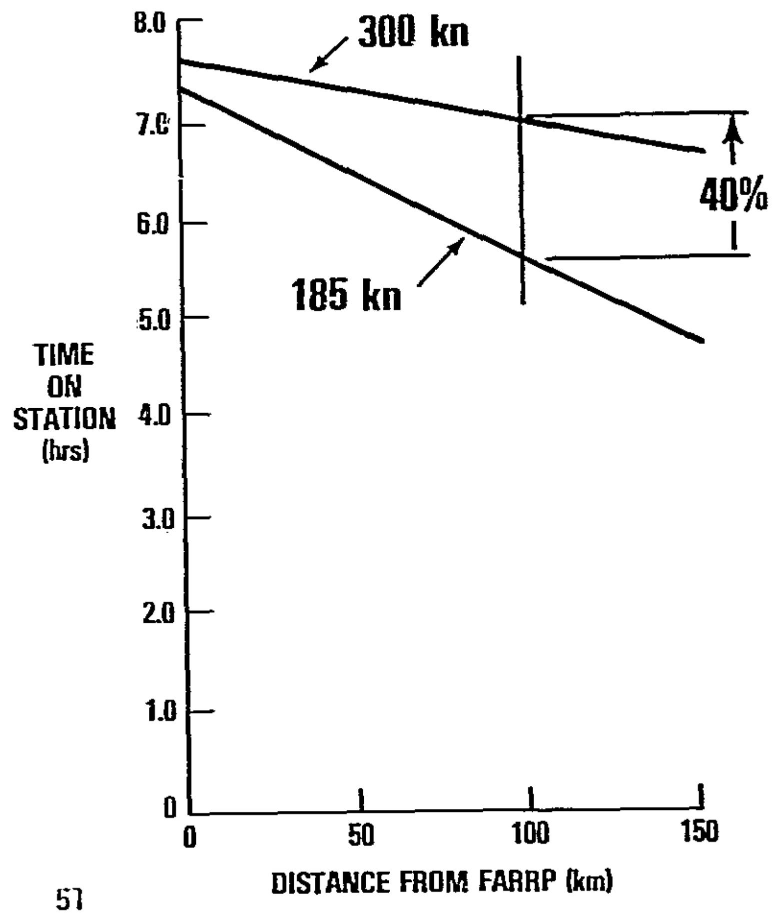
This surveillance mission represents an important function that will be increasingly critical on extended battlefields. The primary variable selected (distance from surveillance site to a forward area rapid refueling point (FARRP)) was found to be a critical parameter during the scenario play. Since FARRPs were frequently lost to enemy action, extensive lateral and rearward distances were required to rearm/refuel in many scenarios.

CAVALRY SURVEILLANCE



Surveillance Flight Mode:
- 33% NOE
- 33% Contour
- 33% Hover

En route speed — Contour
Fuel reserve — 30 min
Refuel time at FARRP — 10 min



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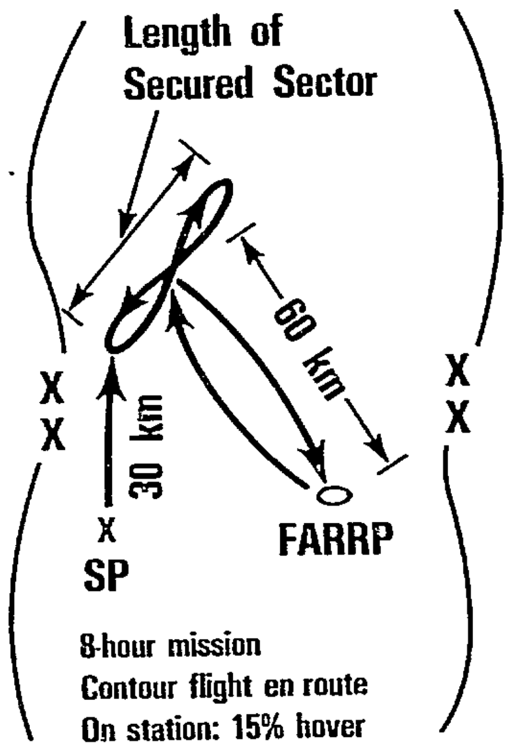
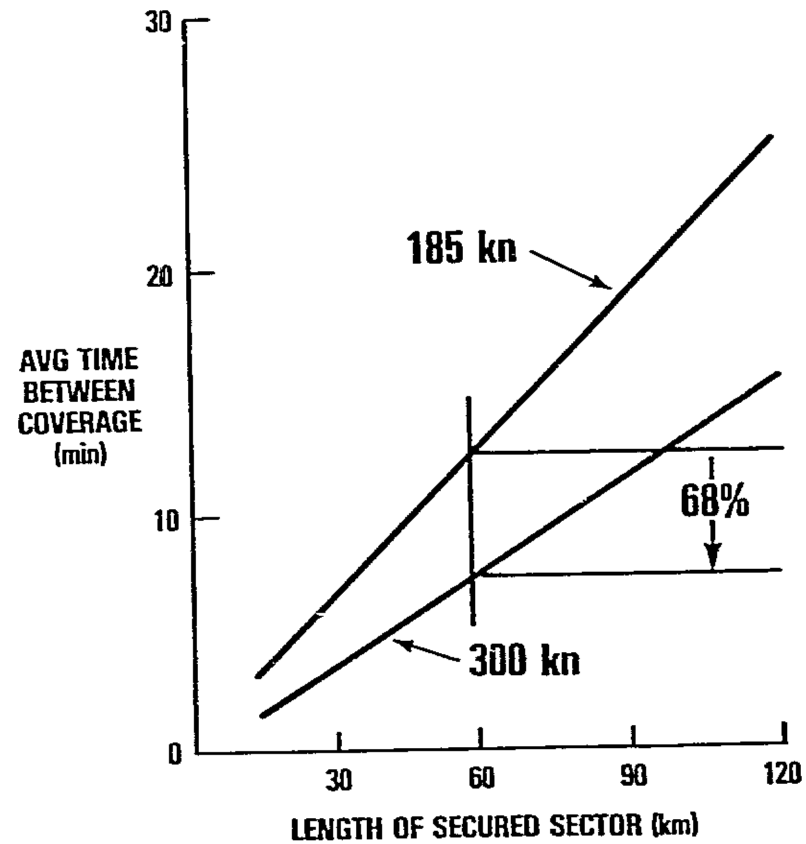
The class described on this chart resembles in some respects the previous surveillance mission. However, this mission class is so important to extended battlefield doctrines that it is included with substantially different input parameters, a different MOE, and a different primary variable. In this example, even a relatively close FARRP location did not diminish speed as an important mission asset.

CAVALRY SECURITY



8-hour mission
Contour flight en route
On station: 15% hover
85% contour
Maintain 30-min reserve
Refuel time – 10 min



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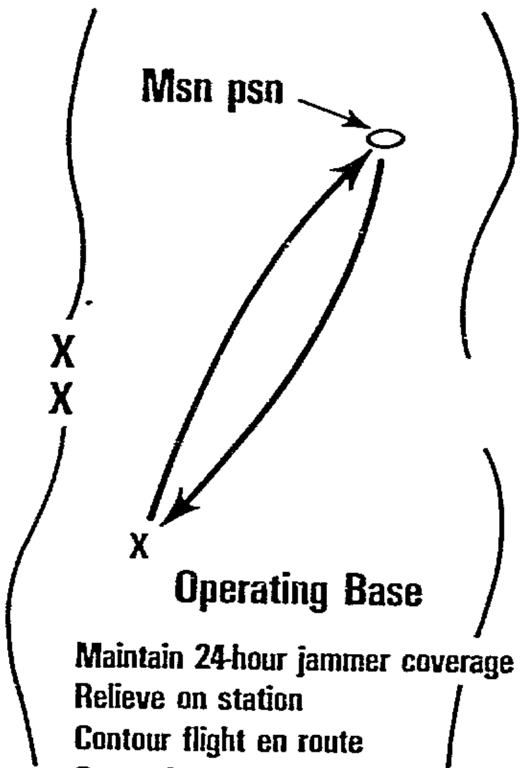
This Special Electronic Mission Aircraft (SEMA) mission involves an airborne jammer flight profile and does not imply that LHX is an appropriate SEMA candidate for the many missions within that category.

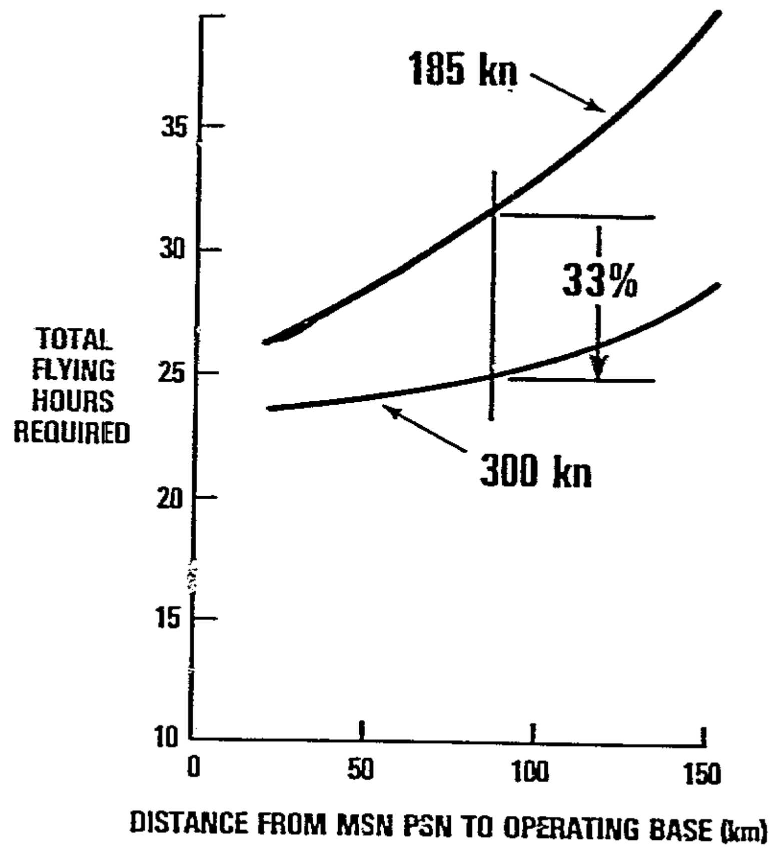
The mission represents a communication jamming role. It does not specifically address whether LHX is proper for SEMA roles in general and avoids the controversy over whether jammers and ELINT systems should be on the same aircraft. Instead, it provides another demonstration that speed capability can contribute positively to time-on-station missions even when speed in the mission area may not be of importance.

SEMA



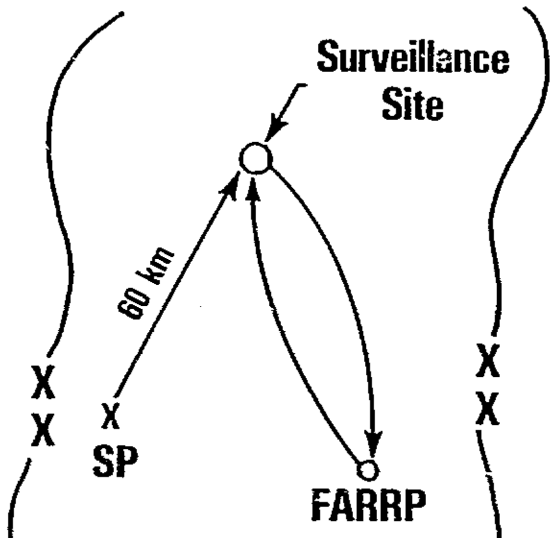
Maintain 24-hour jammer coverage
Relieve on station
Contour flight en route
On station flight
- 80% loiter
- 15% climb
- 5% idle

No unscheduled aborts

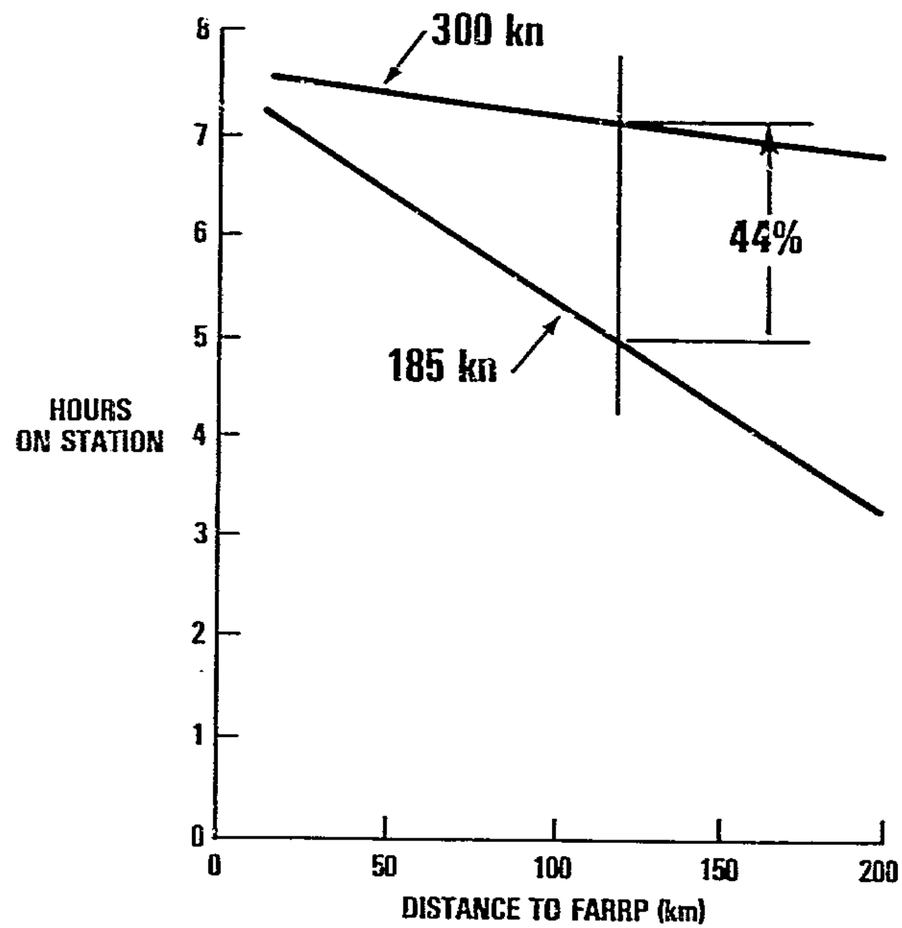


The mission class presents another perspective on the importance of speed to endurance on station. This condition could be representative of a cavalry squadron commander directing a critical engagement or of numerous similar situations.

PRESENCE ON SCENE



8-hour mission
Max time on station
10 min refuel time
Flight modes:
  Contour en route
  25% hover, 25% contour, 50% NOE on site
Maintain 30-min reserve



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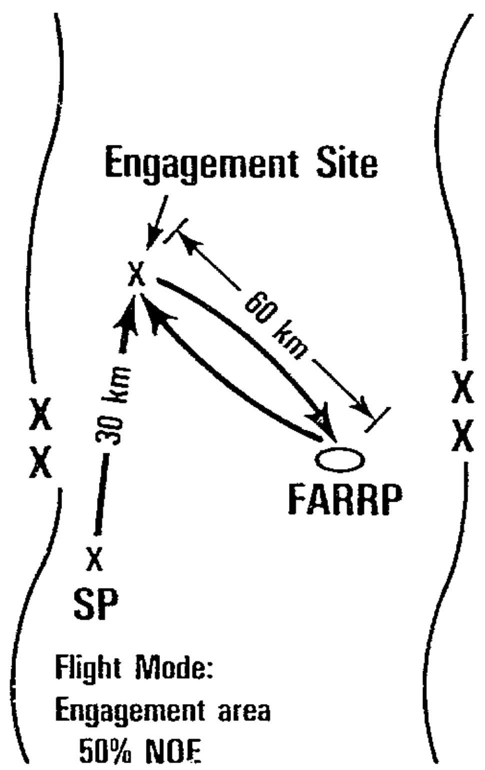
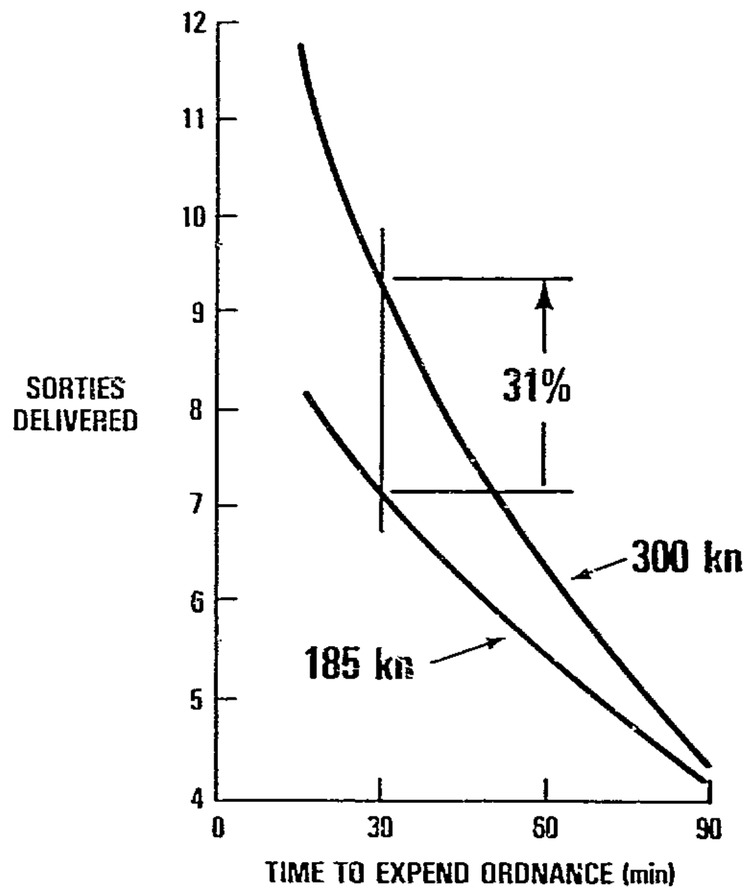
Productivity, or mission generation, is important to aircraft efficiency, but speed may not contribute proportionately for many missions. In this example, the relative improvement of the 300-knot tilt-rotor design is less than the 62 percent speed differential from the baseline. In addition, as the battle becomes more intense and ordnance is expended rapidly, the improvement factor increases most rapidly. This perspective is quite different from many early assessments that considered attack helicopter performance only in the engagement phase of a total mission. During the engagement phase, it has been shown that pop-up maneuver from hover or mild lateral accelerations are most effective. However, considering a total battle period, the turn-around time between rearmings is most critical as the battle intensity is the greatest.

ATTACK SORTIES DELIVERED

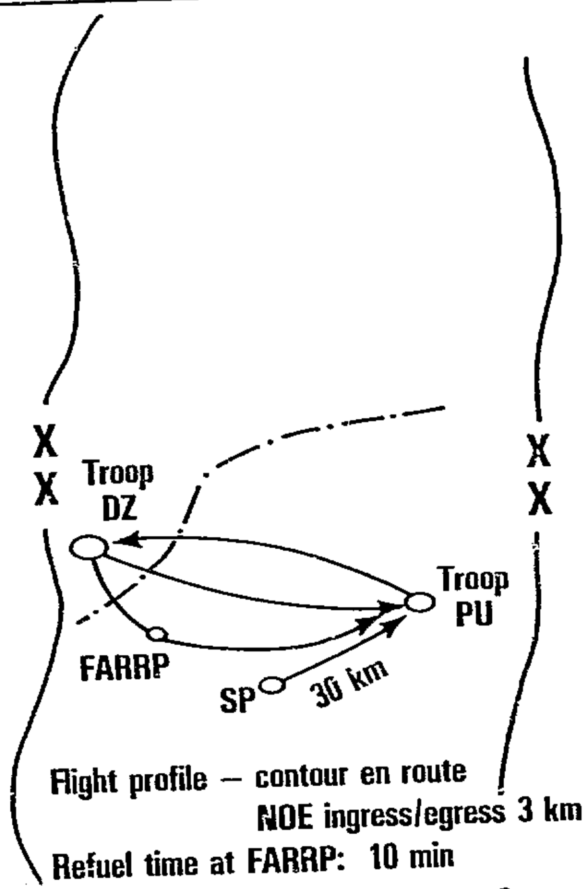


Flight Mode:
Engagement area
50% NOE
50% Hover
Contour en route
15 min rearm time at FARRP

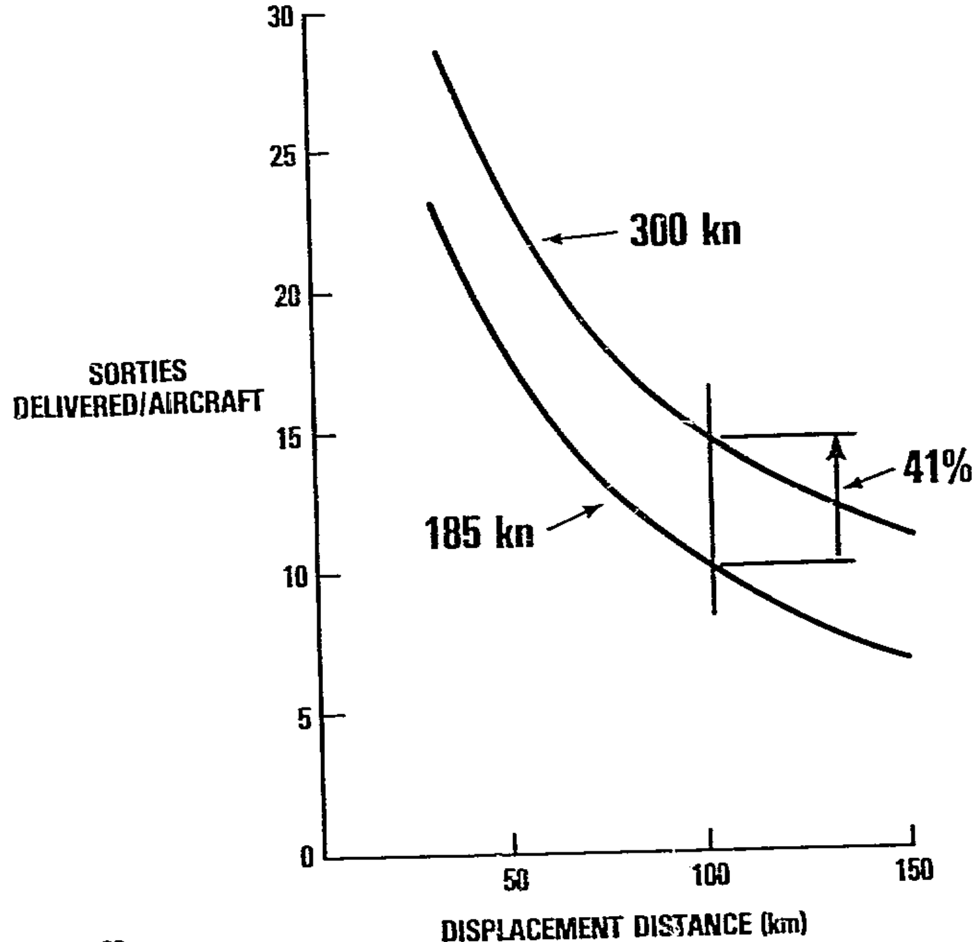


This productivity mission is typical of many transport and utility missions. The parameters are established for a lateral troop displacement, and the MOE and principal variable are straightforward.

TROOP DISPLACEMENT



Flight profile – contour en route
NOE ingress/egress 3 km
Refuel time at FARRP: 10 min
Troop load: 3 min; troop unload: 0
Return leg thru FARRP: disp dist + 25%
Mission time: 8 hr



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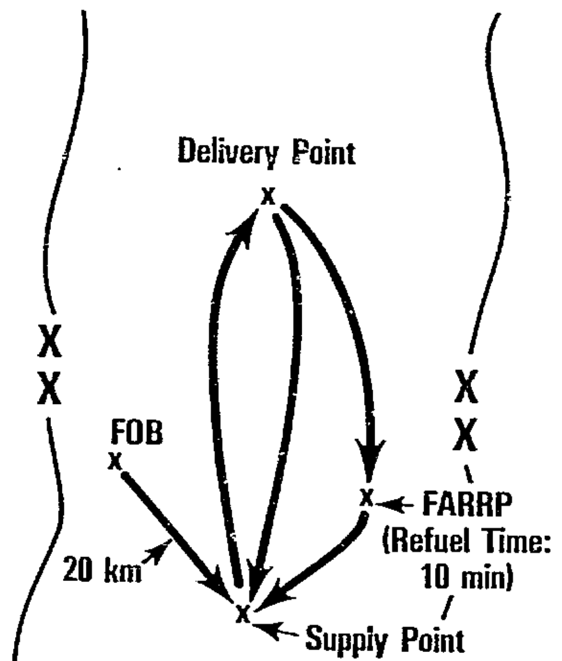
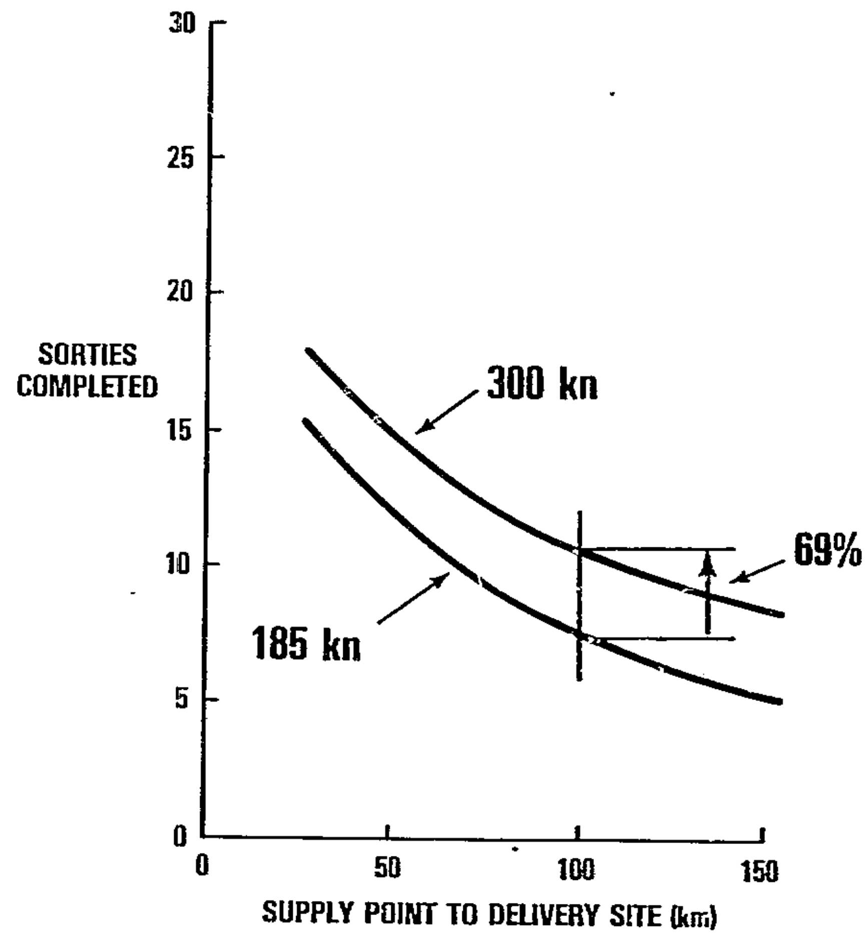
This class of productivity missions is similar to the troop displacement mission, but its parameters are more appropriate to common resupply missions. Again, the MOE and principal variables are straightforward.

RESUPPLY SORTIES DELIVERED



Msn length– 8 hr
Supply loading time – 8 min
Supply unloading time – 4 min
Flight mode – contour en route
ingress/egress 3 km NOE
load/unload idle
Return via FARRP increases
return leg length by 15%



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This chart provides a summary of the improvement factors for the 11 mission classes by comparing the 300-knot tilt-rotor configuration to the 185-knot baseline. The spectrum of missions is sufficiently broad and representative that a simple average could be expected to provide a meaningful measure.

Nevertheless, all of these mission classes are not of equal importance and a simple averaging results in equal weighting. To assess another weighting, each mission class was assigned a simple weighting factor using a simplified Delphi technique. The resulting weighting factors and adjusted MOEs are displayed. Although individual MOEs vary substantially, the average MOEs varied little after the selected weighting factors were applied.

Two other weighting factor distributions were derived with similar results.

RELATIVE VALUE

(IMPROVEMENT OVER 185-KN BASELINE DESIGN, PERCENT)

MISSIONS	UNWEIGHTED MOEs 300-kn TILT-ROTOR	WF	WEIGHTED MOEs 300-kn TILT-ROTOR
Time to scene	46.0	1.2	55.2
Medical evaluations	44.0	1.0	44.0
Mass to scene	158.0	1.3	205.4
Airmobile intercept	120.0	0.7	84.0
Surveillance	40.0	0.9	36.0
Security	68.0	0.9	61.2
SEMA	33.0	0.8	26.4
Presence on scene	44.0	1.0	44.0
Attack	31.0	1.3	40.3
Troop displacement	41.0	1.1	45.1
Resupply	69.0	0.8	55.2
Average	63.1	1.0	63.3

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As reported in SPC Report 730, the influence of speed on vulnerability was apparent for many of the LHX missions in the scenarios played. However, this factor was not generally quantified since this issue is the specific subject of a complementary study being conducted in parallel by Grumman Aerospace Corporation.

The observations of the participants of this study are reported in SPC Report 730 and summarized on the facing chart. A few observations warrant specific comment:

- During many missions, all LHX candidates were flown NOE at the same speed when the threat was the greatest. The faster aircraft configurations tended to have larger presented areas and thus received more hits.
- Even if the clear advantage of speed in helicopter air-to-air engagements is discounted by the argument that helicopters operate in the same air defense environment as the rest of the Army, a fast response to Soviet airmobile and airborne operations in our rear areas will benefit from a high-speed capability.
- The emphasis of most past analyses and field tests pertaining to survivability has been on the engagement portion of attack helicopter mission profiles. As a result, many survivability benefits of speed have not been adequately assessed during other phases of typical missions.

VULNERABILITY

- The influence of speed on vulnerability was not resolved
- Against ground threats, the advantages of speed tend to be offset by a consequence of speed, i.e. larger presented area
- Against helicopter threats, a speed advantage is important, especially when the threat has superior armament
- Against attack/fighter airplane threats, vulnerability is essentially insensitive to speed within the speed variations considered

VI. COSTS AND MILITARY WORTH

Unit acquisition costs were computed using the methodology described in SPC Report 730 with modifications to account for the different system complexity of tilt-rotor designs.

Research and development and other non-recurring costs were derived from the ASH Baseline Cost Estimate (BCE). The LHX helicopter and baseline tilt-rotor non-recurring costs were scaled from the ASH BCE; the airframe and engine costs were varied by the square root of the DCPR[1] weight for the airframe and by the square root of installed power for the engines. ASH BCE visionics costs were assumed with deletions of all mission equipment except basic flight communications and navigation equipment. These non-recurring costs were amortortized over 4,000 aircraft to produce the average unit costs displayed on the facing page.

To provide a perspective on additional costs that might be incurred because of the increased complexity of system components, all components that would have design considerations unique to the tilt-rotor concept (e.g., rotors, drive systems, flight controls, tilt actuators) were identified in the component weight buildup. The unique components made up about 30 percent of the DCPR weight. An examination of these components as implemented on the XV-15 displayed only small increases in technical complexity compared to the UH-60A helicopter. In order to test the sensitivity of uncertainties in technical complexity, cost penalties of 25 and 50 percent were assigned to unique components.

For recurring costs, Cost Estimating Relationships (CERs) developed for OSD's Cost Analysis Improvement Group (CAIG) were used. Cost penalties were assigned to unique tilt-rotor components to test the uncertainty of producing components with which we have little production experience. Since the cost per pound of these components is relatively low compared to the costs of engines and avionics, the cost variation estimate varies little with added complexity factors. The average unit cost was based on a production lot of 4,000 aircraft produced at 600 per year with a 90 percent learning curve.

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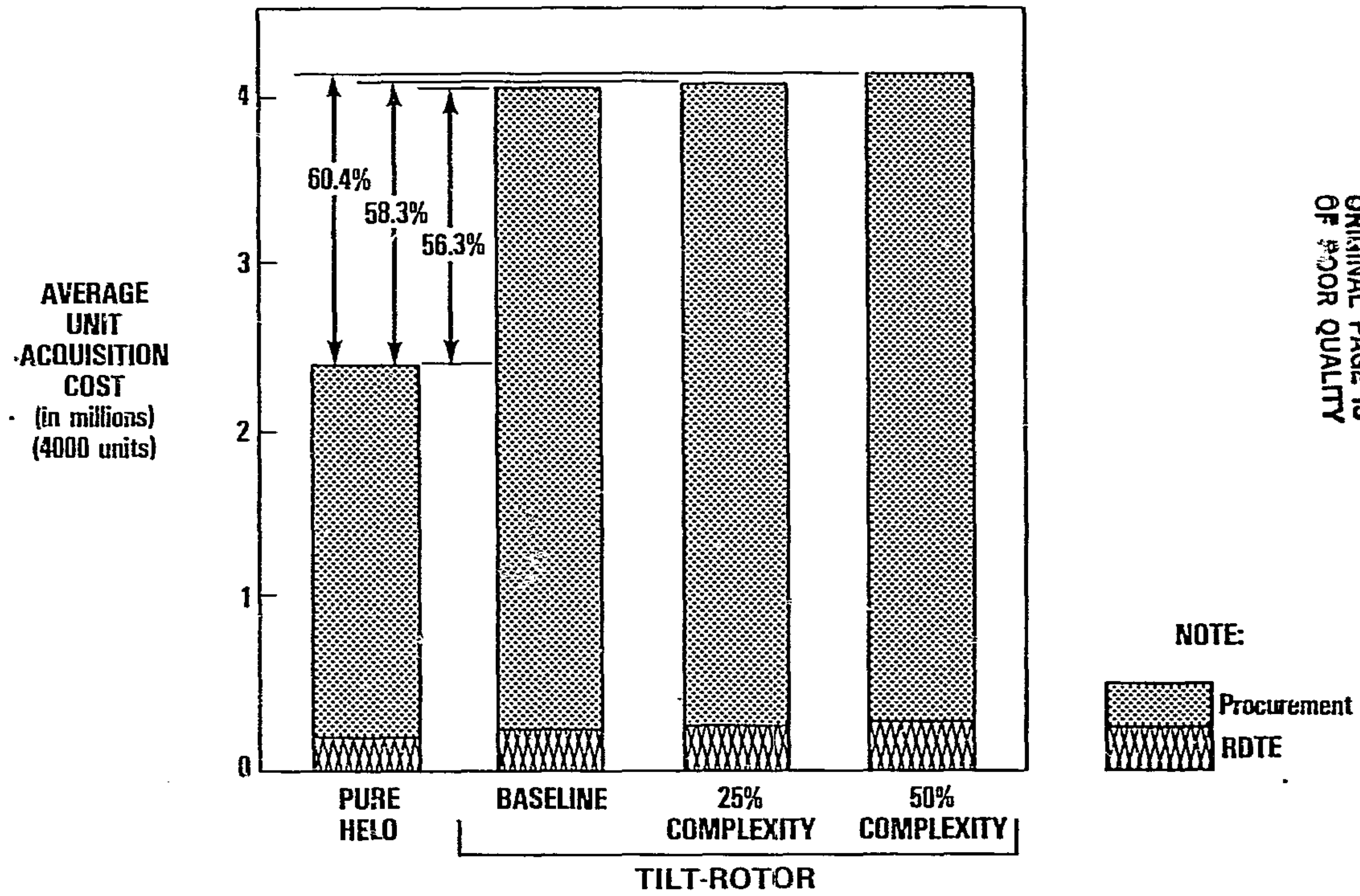
[1]Defense Contractor's Planning Report.

UNIT ACQUISITION COST

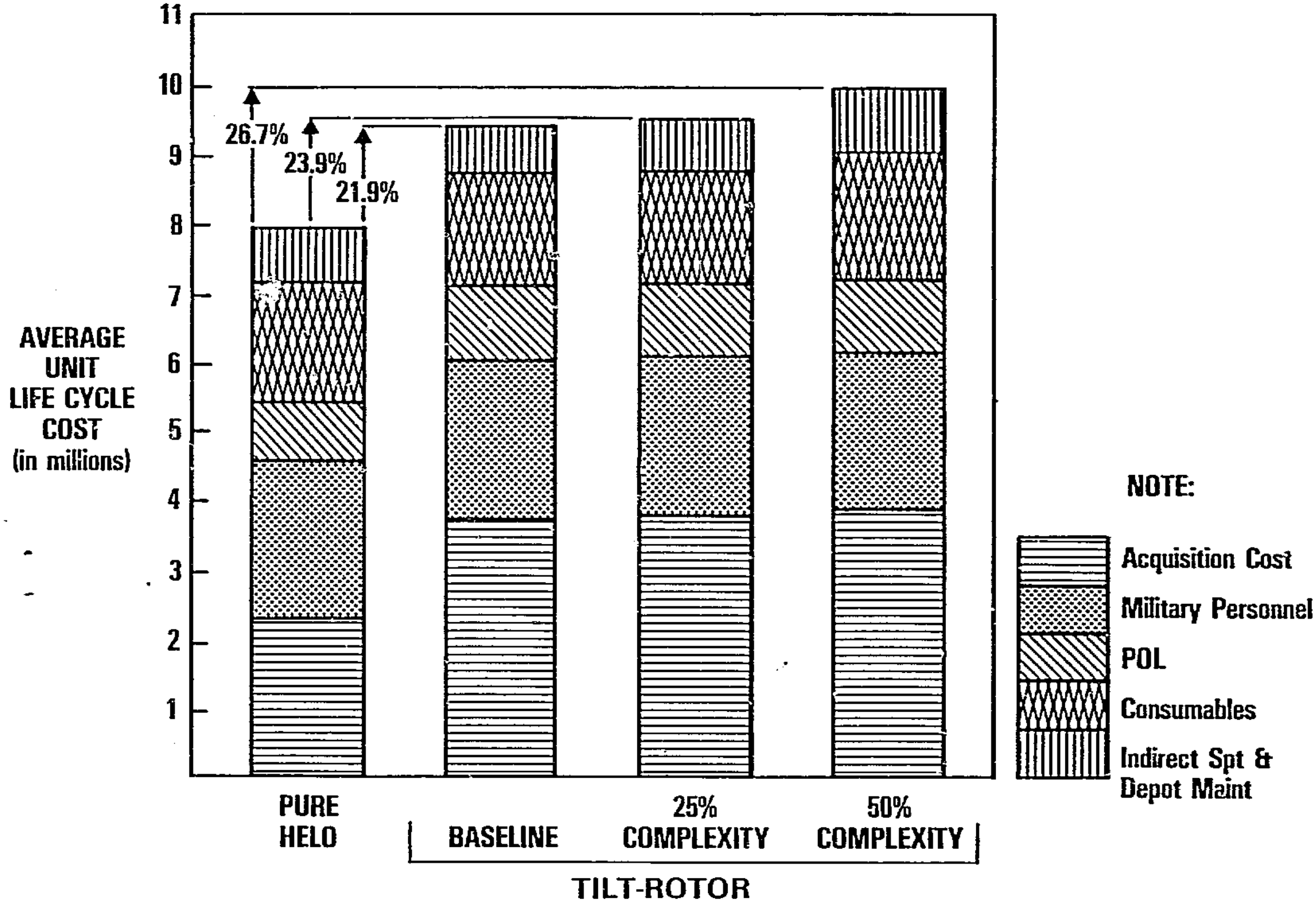
(FY 82 $)



The life cycle costs shown here add personnel and other operating costs over a 20-year life cycle. Usage is based on current peacetime flying hour rates. The depot maintenance factor includes an increment for accident damage repair as well as major overhauls. Component service lives comparable to those being projected for the UH-60A and on-condition replacement of engines and major dynamic systems are assumed in accordance with modern practices.

There is substantial uncertainty in the absolute magnitude of most of the indicated cost elements. However, the costs were computed consistently for the major alternatives. For this reason, these cost projections should provide reasonably accurate relative costs but should be used with caution when comparing the known costs of current systems. The cost methodologies used here represent the state-of-the-art in costing techniques but have not proven to be a reliable predictor of the absolute costs of conceptual helicopter designs.

ESTIMATED LIFE CYCLE COST



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The military worth indices shown here reflect the fact that higher speeds are obtained at lower costs with tilt-rotor technology than with high-speed helicopter alternatives. The result is a substantially greater military worth for the spectrum of missions considered.

A tilt-rotor LHX offers other potential advantage beyond the mission spectrum for which relative values were computed. Some of these are addressed on a subsequent chart.

MILITARY WORTH

AVERAGE MOEs

	BASELINE	25% COMPLEXITY	50% COMPLEXITY
$\frac{\text{Relative Value}}{\text{Relative Cost}}$	$\frac{1.631}{1.219} = 1.34$	$\frac{1.631}{1.239} = 1.32$	$\frac{1.631}{1.267} = 1.29$

WEIGHTED MOEs

	BASELINE	25% COMPLEXITY	50% COMPLEXITY
$\frac{\text{Relative Value}}{\text{Relative Cost}}$	$\frac{1.633}{1.219} = 1.34$	$\frac{1.633}{1.239} = 1.32$	$\frac{1.633}{1.267} = 1.29$

The previous LHX speed assessment considered helicopter configurations with speed capabilities of 185, 220, and 250 knots. Although this speed band displayed significant variations in costs and military values for the mission considered, the resulting military worth indices indicated only that the slowest configuration would have the lowest military worth but not, perhaps, by a decisive factor, i.e. on the order of 15 percent. On the other hand, the military worth of the tilt-rotor has been shown to be about twice that of the other higher speed alternatives. In addition, the speed and range efficiency advantages inherent in the tilt-rotor's unique configuration offer other potential advantages that deserve special mention.

With vertical flight efficiency comparable to the best helicopters and cruise efficiency (speed and range) approaching that of modern turbo-prop airplanes, a tilt-rotor LHX could be capable of many military missions that cannot now be accomplished--many of which are of high national importance. The Son Tay raid, the Mayequez incident, and the Iranian hostage rescue attempt are examples of missions that were marginally within the capabilities of helicopters. These missions were compromised by the technical limitations inherent in helicopters, and many other potential missions of equal national importance were not attempted because of technical limitations. Although missions of this type occur with low frequency and are virtually impossible to predict in detail, such missions will continue to arise and often involve issues of high national priority.

In addition to these important but infrequent missions, there are hundreds, perhaps thousands, of examples of civil and military emergencies where life saving rescue operations have failed because of time response and range limitations of even modern helicopters.

Although difficult to claim as essential and with benefits not readily quantifiable, the advantages, to both military and civil users of accomplishing near portal-to-portal travel have long been an unrealized goal of transportation designers and users alike. While an operational tilt-rotor will not immediately result in such a universal capability, many trips that do not involve multimode legs could be accomplished efficiently by a single vehicle that combines the vertical flight efficiency and low noise levels of modern helicopters with the cruise efficiency of an airplane. As was the experience with helicopters, the development and deployment of such a capability to meet essential military needs could result in an increased capability for a wide range of important roles that might not otherwise be realized.

OTHER TILT-ROTOR ADVANTAGES

- ► A substantial range advantage (better than two over advanced helicopters)
  - Better specific range (~ 0.52 vice ~ 0.33 nmi/lb at low altitude)
  - Efficient high altitude cruise ($\sim 55\%$ better than SL; no altitude range advantage for helicopters)
- ► Counter air operations
  - Only a tilt-rotor LHX assures a speed advantage over Hind follow-on
  - A tilt-rotor LHX offers best response to Soviet airmobile operations
- ► Exceptional capabilities for high priority, long range missions (raids, extractions, rescue, MAAG/mission support)

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VII. CONCLUSIONS AND RECOMMENDATIONS

These conclusions follow from the data presented and do not require further amplification.

LHX TILT-ROTOR ANALYSIS
CONCLUSIONS

- Evolving technology could provide an LHX with speed capabilities up to twice those of the most modern operational helicopters with an operational capability by the mid-90s
- The value of speed is most apparent when performance during the period and in the context of a full battle day is considered rather than by mission or by mission segment
- If the final requirement validates the need for greater speed rather than the minimum unit cost alternative (conventional helicopter), the tilt-rotor appears to be the solution with the greatest military worth for normal battlefield missions and with the greatest capability for meeting uncertainties of future needs
- If a need for 300-knot speed capabilities for LHX is validated, the lack of a competitive technology base for tilt-rotor designs may present difficulties during the early acquisition phases

The urgency for beginning an LHX development not later than FY 86 is presented in SPC Report 700 and more recent efforts by the U.S. Army Aviation Center. During the intervening period, it is important that the XV-15 aircraft be employed in a wide variety of operational missions in order to identify any impact this unconventional design might have on operational missions. In addition, alternative fuselage designs for utility, scout, and attack variants should continue to be worked, probably by use of mock-ups. The disc loading issue should be addressed early, and detailed engineering assessments of alternative disc loading design points should be completed.

It is important that an engine development begin soon. Since it is unlikely that the user will confirm his needs promptly, the issue of how to resolve the engine size requirement remains outstanding. One alternative that should be considered is sizing the engine at about 800 hp, which would be suitable for a twin engine helicopter or a 3-engine tilt-rotor LHX. An adequate basis for recommending this solution does not exist at this time.

LHX TILT-ROTOR ANALYSIS
RECOMMENDATIONS

Provide results from the ADTE, ADOCS, ITRP, ACAP, and tilt-rotor programs to support an ED start for LHX in FY 86

Expand the tilt-rotor program to expose the XV-15 research aircraft to simulated combat missions and to broaden the technology base beyond the current technical base

Establish a "most likely" power requirement for the ATDE promptly so that the user's need will not be delayed or constrained by technical capabilities